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Division

Summary of Field Work and Other Activities 1988

Ontario Geological Survey
Miscellaneous Paper 141

edited by A.C. Colvine, M.E. Cherry, Burkhard O. Dressler,
P.C. Thurston, C.L. Baker, R.B. Barlow, and Chris Riddle

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FOREWORD

During 1988, the Ontario Geological Survey carried out a large number of independent geoscience studies. In addition, studies were undertaken in cooperation with regional geological staff, personnel from universities, and private consulting firms. Special Geoscience programs were also undertaken in several areas under the Canada–Ontario Mineral Development (COMDA–ERDA) Agreement and with Northern Development Fund support. Project involvement by the various participants is summarized in the individual reports. Separate funding for a number of regional stimulation projects was provided and funding acknowledgements are included in the individual summaries.

The locations of the areas investigated are compiled on two maps of the province at the beginning of this report. Preliminary results of field work and other research are outlined in this summary, which contains reports prepared by leaders and principal investigators for each of the projects. In these reports, some emphasis has been placed on the economic mineral resource aspects of the different investigations. The aim of the Ontario Geological Survey in producing this summary immediately following the field season, is to provide quick access to new information for mineral resource evaluation of these areas, which will be of value in current mineral exploration and resource planning. In addition, the wide spectrum of research in this report is of interest to the geoscience community as a whole.

Survey geoscientists will conduct more detailed research and analysis of the field work data through the winter and will be preparing reports on these investigations for publication. In the interim, uncoloured preliminary geoscience maps with comprehensive marginal notes will be released for distribution, mainly during the winter of 1988–1989. Notices of the releases will be mailed to all persons or organizations on the Mineral Resources Group publication release notification list, and will be published in the technical journals and other media.

V.G. Milne

Director
Ontario Geological Survey

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			LENGTH		
1 mm	0.039 37	inches	1 inch	**25.4**	mm
1 cm	0.393 70	inches	1 inch	**2.54**	cm
1 m	3.280 84	feet	1 foot	**0.304 8**	m
1 m	0.049 709 7	chains	1 chain	20.116 8	m
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			AREA		
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1 m^2	10.763 9	square feet	1 square foot	**0.092 903 04**	m^2
1 km^2	0.386 10	square miles	1 square mile	2.589 988	km^2
1 ha	2.471 054	acres	1 acre	0.404 685 6	ha
			VOLUME		
1 cm^3	0.061 02	cubic inches	1 cubic inch	**16.387 064**	cm^3
1 m^3	35.314 7	cubic feet	1 cubic foot	0.028 316 85	m^3
1 m^3	1.308 0	cubic yards	1 cubic yard	0.764 555	m^3
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1 L	1.759 755	pints	1 pint	0.568 261	L
1 L	0.879 877	quarts	1 quart	1.136 522	L
1 L	0.219 969	gallons	1 gallon	**4.546 090**	L
			MASS		
1 g	0.035 273 96	ounces (avdp)	1 ounce (avdp)	28.349 523	g
1 g	0.032 150 75	ounces (troy)	1 ounce (troy)	**31.103 476 8**	g
1 kg	2.204 62	pounds (avdp)	1 pound (avdp)	**0.453 592 37**	kg
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			CONCENTRATION		
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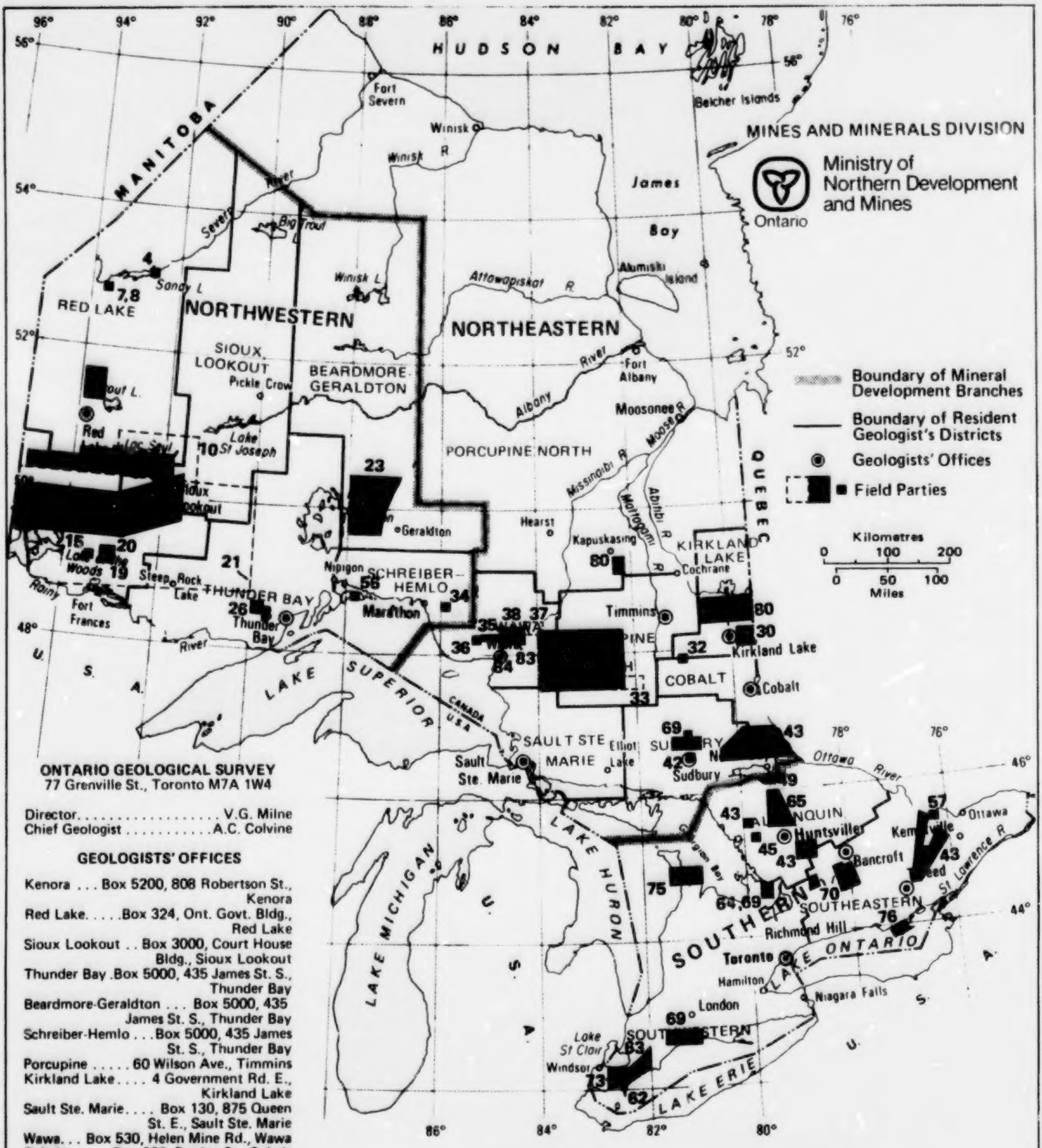
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LOCATION OF FIELD PROJECTS, 1988

ONTARIO GEOLOGICAL SURVEY

ONTARIO GEOLOGICAL SURVEY
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GEOLOGISTS' OFFICES

Kenora . . . Box 5200, 808 Robertson St., Kenora
Red Lake. . . . .Box 324, Ont. Govt. Bldg., Red Lake
Sioux Lookout . . Box 3000, Court House Bldg., Sioux Lookout
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Porcupine . . . . . 60 Wilson Ave., Timmins
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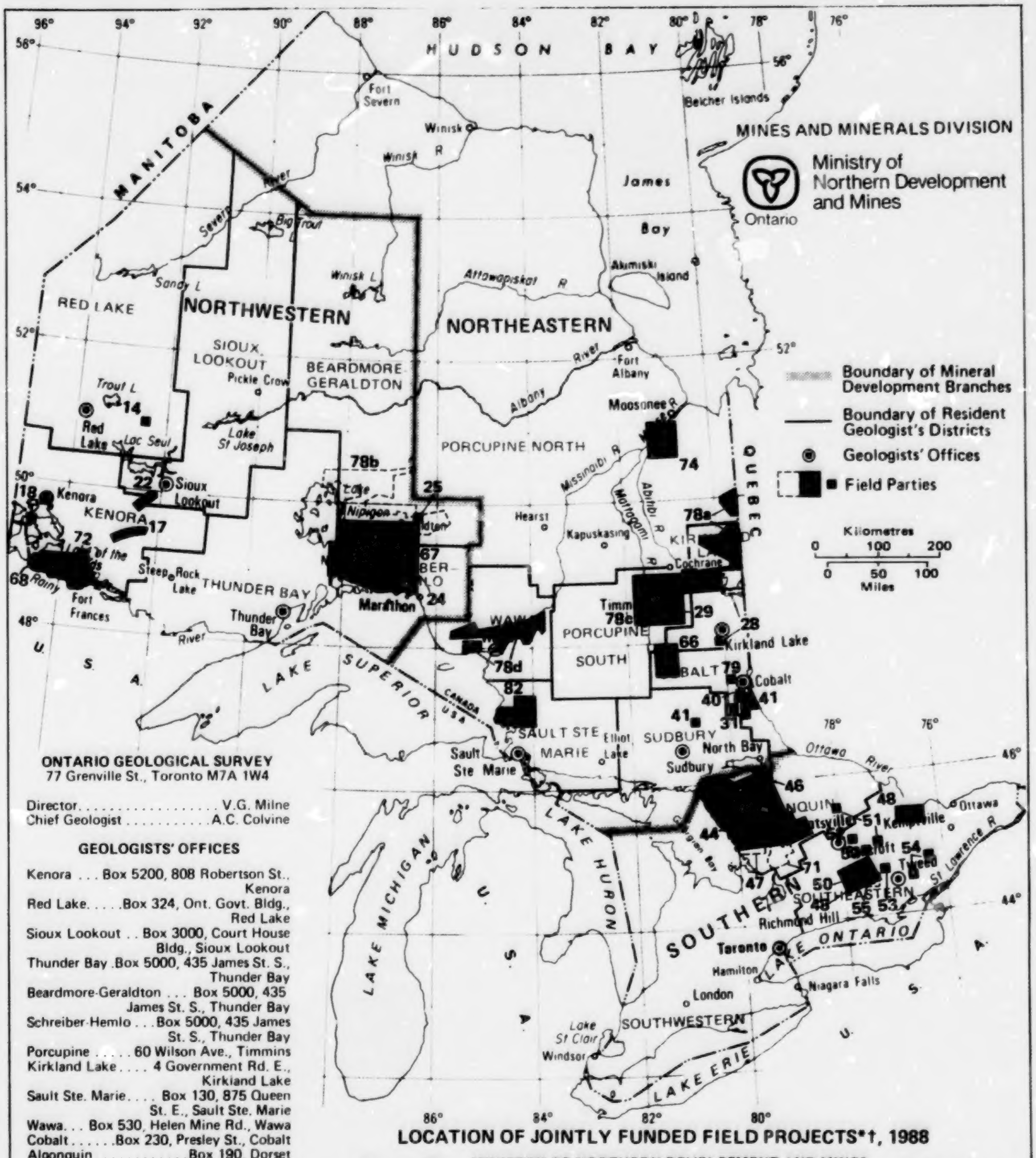
Location of Field Parties, base budget, 1988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GEOLOGISTS' OFFICES

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LOCATION OF JOINTLY FUNDED FIELD PROJECTS*†, 1988

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ENERGY, MINES AND RESOURCES CANADA
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*These projects are part of the five year Canada-Ontario 1985 Mineral Development Agreement (COMDA) a subsidiary agreement to the Economic and Regional Development Agreement (ERDA) signed by the governments of Canada and Ontario

†These projects are part of the five year 1987 Airborne Geophysical Survey Program for Northern Ontario which is funded by the Northern Development Fund

Location of Field Parties, jointly funded projects, 1988

Precambrian Geology Programs

1. Summary of Activities, 1988, Precambrian Geology Section

A.C. Colvine

Chief Geologist, Precambrian Geology Section, Ontario Geological Survey, Toronto.

As reported last year, several new major initiatives are underway in the Precambrian Geology Section. In each of these initiatives, interdisciplinary working groups have been established, principally to conduct field–based mapping research as a means to better understand fundamental geological problems in the Precambrian Shield. These constitute both geological–geographic groups, such as that in the Wabigoon Subprovince, and thematic groups, such as those investigating gold mineralization and major structures throughout the Shield in Ontario. For ease of reference, the work of these groups is presented in this volume on a geographic basis. The first paper in each section includes a summary of the work in that area. External funding sources are identified for applicable projects.

The most comprehensive initiative is the "Geology of Ontario" project, which encompasses the work of all Sections of the OGS. This project will synthesize our present knowledge of the geology of the Province and will result in a publication scheduled for release in 1991, the centennial of the OGS and its predecessors. Accompanying the volume will be a set of maps, at a scale of 1:1 000 000, covering bedrock geology, tectonics, metallogeny, magnetics, gravity, and Quaternary geology. The bedrock geology map is presently partially completed and is scheduled for release in 1989. It reflects the significant advances in our understanding over the last twenty years, since the release of the current 1 inch to 16 mile geology map of Ontario. While the volume and maps will be important references, the project will also have a second important result: a comprehensive reappraisal of both strengths and weaknesses of our knowledge of the Province's geology and mineral resources. As such, it will influence future project planning.

Activities in Northwestern Ontario during the 1988 field program in particular reflect this reappraisal. This area constitutes more than one–third of the Archean Shield in Ontario, but much of it is relatively inaccessible and therefore expensive to map. Some areas are covered by recent detailed mapping, but much is only covered by old reconnaissance mapping. This year's mapping projects had two objectives: firstly, to provide data on specific areas of interest, and secondly, to contribute to a reappraisal of the geological framework of the Northwestern Shield in order to identify priority areas for mapping and to establish the appropriate scale for this work. Three principal subjects of study are apparent in the summaries that follow:

1. large–scale structures or deformation zones, which are the principal host to gold mineralization. In addition, these form the boundaries of subprovinces which represent terrains of different geological style and mineral potential.
2. discrimination of platformal volcanic and sedimentary sequences in greenstone belts. From this work, it has become clear that greenstone sequences are composites of several ages and environments of volcanism, each with different mineral potential. In addition, this work is elucidating the early evolution of the Archean crust.
3. regional study of granitic rocks, to subdivide them by age and composition. While the "pink rocks" are generally considered of low mineral potential, they might better be considered of "unknown" potential. While detailed mapping of such rocks is not justified, mapping of larger areas at 1:100 000 scale can readily subdivide them and identify smaller areas of higher potential.

Further mapping in Northwestern Ontario will focus on specific favourable structures or greenstone belts, and will include regional mapping of granitic terrains.

The western part of the Wabigoon Subprovince has benefited from extensive detailed mapping over the last five years, as described in this and preceding Summaries of Field Work. We are now in a position to use this data base in the preparation of synoptic reports on the Rowan–Kakagi and Lake of the Woods greenstone belts, and of 1:100 000 belt–scale maps. Other mapping projects in the Wabigoon Subprovince continued in 1988, with a focus on the Beardmore–Geraldton tectonic belt and the Dinorwic–Sioux Lookout area.

The Abitibi Greenstone Belt is the largest exposed Archean greenstone belt in the world. To date, the Ontario portion of this belt has been responsible for gold and base–metal production approaching $100 billion in current dollars, and extensive exploration for new deposits continues. While many areas of the Abitibi Belt have been mapped, by many different geologists, there are still gaps in our knowledge. In addition, the following new data indicate that it is now appropriate to re–investigate the main Abitibi Greenstone Belt.

1. High precision geochronology indicates that belt–wide stratigraphic correlations of similar volcanic types cannot be assumed. Consideration must be given to a tectonic assembly of the belt, rather than a simple intact stratigraphy.
2. A short, deep crustal seismic transect across the belt, supported by the OGS as an addition to the Kapuskasing Lithoprobe traverse, has identified low angle discontinuities beneath the Blake River and Kinojevis groups, possibly representing tectonic rather than conformable boundaries.
3. Recently acquired, detailed gravity and high resolution magnetic and electromagnetic data are available for large portions of the belt.

Further mapping in the Abitibi will be targeted not only at filling gaps in map coverage, but also at improving our understanding of the major structures, which host gold mineralization, and of the stratigraphy and structure of volcanic sequences, which host base–metal deposits.

Detailed mapping in the Hemlo area continued this year, as reported in an extended summary. Preparation of an interim report and maps from this work is in progress.

The Wawa area has been the focus of detailed mapping over the past ten years. Since 1985, this program has been supplemented by mapping in the Mishibishu Lake Belt. This work will be proceeding to a synoptic report and map of the western part of the Michipicoten greenstone belt. Mapping of the eastern part of the belt is less recent, and therefore, the available geological data base is being supplemented by structural and alteration studies to assist further gold exploration.

The Proterozoic holds potential for a large variety of metallic and industrial mineral deposits, and this is reflected in the variety of mapping and commodity–specific projects undertaken this year. Extensive mapping of the Central Metasedimentary Belt of the Grenville Province over several years is leading to preparation of a series of 1:50 000 compilation maps. Detailed mapping in the Parry Sound area is contributing to our understanding of the very complex geology of the Grenville Province. This understanding is essential if we are to successfully target areas of high mineral potential.

Several additional topics are also reported in this volume. The Petroch geochemical data base is now sufficiently large and accessible to be a significant resource. Some of its applications are reported. Classification of volcanic rocks, discrimination of alteration associated with mineralizing systems, and characterization of intrusions related to gold mineralization are but three uses of Petroch currently being investigated. The computerized field note system has been expanded to encompass computerized map display, which will enhance data capture, improve efficiency of field mapping, and result in more efficient rapid production of published maps. Applications of both satellite imagery and side scan radar are being investigated as aids to mapping.

Computerized map representation and geophysical, geochemical, and remote sensing data highlight the need for better means of taking advantage of the wealth of existing data which is currently available. The Wawa data integration project is one of several pilot projects underway to investigate ways of using all types of existing data to increase efficiency and provide the highest quality in new mapping projects.

As first reported last year in the summary of Section activities, revision of the 1:250 000 scale compilation maps is underway. This map series has consistently been widely used by the mineral exploration industry. The revised maps will incorporate advances in our geological data base, and will show enhanced mineral occurrence information. Release of the first such revised map – the Atikokan–Lakehead sheet – is planned for 1989.

During 1988, the Section continued to play a strong role in the Provincial, National, and International geoscience community. Seminars and workshops were presented throughout the Province, in order to highlight our continuing work. Selected scientific papers were presented at several national and international meetings.

2. Project Number 88–23. Geology of Ontario: An Update

P.C. Thurston

Geologist, Precambrian Geology Section, Ontario Geological Survey, Toronto.

The geology of Ontario project is to provide an up-to-date summary of the geology of the Province, with the goal of producing all material by the centennial of the OGS in 1991. The project will be carried out in several stages over the next three years, and will involve personnel from the Precambrian, Engineering and Terrain, and Geophysics and Geochemistry sections within the OGS.

The summary will consist of a map series portraying major facets of the geology of the Province, and an accompanying descriptive volume. The maps, at a scale of 1:1 000 000, include: 1) a geological map; 2) a tectonic map; 3) a metallogenic map; 4) a Pleistocene geological map; 5) a magnetic map; and 6) a gravity map. The volume will deal with the whole Province from Archean to Pleistocene and is intended to include: an introduction and history (5 percent), a descriptive summary of the geology of the Province (40 percent), a thematic section (40 to 50 percent), and a summary with a tectonic emphasis (5 percent). The descriptive section will examine the nature of major rock types and stratigraphic units on a subprovince by subprovince basis in the Archean, and a similar plan will be followed in the Grenville, Paleozoic, and Mesozoic. The thematic section will provide an up-to-date description of the major areas of OGS activity, for example: gold metallogeny, the assessment of mineral potential in felsic volcanic sequences, neotectonics and engineering geology, and hydrogeology. The summary will allow examination of large-scale questions, for example: how the Superior Province was assembled, were there multiple episodes of gold mineralization and do they vary in terms of chemical signature, and whether reactivation of Grenville structures is causing current movement of faults in the sedimentary platform of Southern Ontario.

At present, the legend is complete for the geological map, and editing of the map prior to submission for printing will be complete by early 1989. The tectonic map will be in manuscript form by late 1989, and the other maps mentioned above will follow in sequence. Writing of sections of the volume will commence this winter.

LEGEND FOR THE NEW GEOLOGICAL MAP

The legend for the 1:1 000 000 geological map (Table 2.1) was prepared in late 1987 and consists of a total of 51 units. The philosophy in development of the legend was to portray the advances in our knowledge of lithologic associations and their distribution, and to classify them in a manner that would allow the geological map to be the factual base for a tectonic interpretation. Geological interpretation of most of the Superior Province is complete and is progressing rapidly on the Grenville and the Paleozoic/Mesozoic. Major features which have come out of the legend design process and the compilation thus far are discussed below.

GREENSTONE SEQUENCES

The Superior Province is subdivided into granite–greenstone, sedimentary, gneissic, and plutonic subprovinces. Most subprovinces have rock units of similar age range, structural style and trend, and generally define a block bounded by large-scale shear zones.

The granite–greenstone subprovinces, based upon a compilation by Card and Ciesielski (1986) are, from north to south, the Sachigo, Uchi, Bird River, Wabigoon, and the Abitibi. Thurston and Chivers (in press) have recently subdivided greenstone sequences into four types, two of which are distinct packages and form separated units within the legend. They are described as follows:

1. Platform sequences consist of a basal quartz arenite overlain by iron formation and ultramafic to mafic volcanics, and are shown as unit 1 in the legend. Based upon the presence of abundant shallow water depositional structures, the association of quartz arenite and sedimentary carbonate, and the presence of stromatolites, these sequences are considered to represent shallow water sequences, comparable with platform sequences at passive margins. The quartz-rich character of the sediments and petrographic evidence of a granitoid provenance suggests erosion from widespread granitic areas. As platform sequences are greater than 2.85 Ga and perhaps approaching 3 Ga, they suggest the existance of a pre-2.7 Ga orogenic event. These sequences unconformably overlie -3 Ga greenstones (Donaldson and deKemp 1987) and granitic rocks (Davis and Jackson 1988), and are concentrated in the Sachigo Subprovince and the Wabigoon Diapiric Axis (Thurston *et al.* 1987).

TABLE 2.1. LEGEND FOR GEOLOGICAL MAP.

LEGEND
Ontario Geological Map

PHANEROZOIC

MESOZOIC

51 Jurassic and Cretaceous
Middle Jurassic and Lower Cretaceous
Kaolinitic clay, clay, sand, lignite

PALEOZOIC

Devonian

50 Upper Devonian
Shale

49 Middle Devonian
Limestone, dolostone, shale

48 Lower Devonian
Sandstone, dolostone, limestone

Silurian

47 Upper Silurian
Limestone, dolostone, shale, sandstone, gypsum, salt

46 Lower and Middle Silurian
Sandstone, shale, dolostone, siltstone

Ordovician

45 Upper Ordovician
Shale, limestone, dolostone, siltstone

44 Middle Ordovician
Limestone, shale

43 Lower Ordovician
Dolostone, sandstone

Cambrian

42 Conglomerate, sandstone, shale, dolostone

PRECAMBRIAN

PROTEROZOIC

EARLY TO LATE PROTEROZOIC

41 Carbonatite–Alkaline Intrusive Suite[a]
Carbonatite, nepheline and alkalic syenites, ijolite, fenite, and associated mafic and ultramafic rocks

40 Early to Late Mafic Igneous Rocks[b]
Diabase, gabbro, diorite, ultramafic rocks and granophyre

39 Late Felsic Igneous Rocks
Granite, syenite

GRENVILLE PROVINCE

MIDDLE TO LATE PROTEROZOIC

Central Metasedimentary Belt

38 Late Felsic Plutonic Rocks
Granodiorite, granite, syenite, pegmatite, alkaline granites

37 Mafic and Ultramafic Plutonic Rocks
Diorite, gabbro, peridotite, pyroxenite, anorthosite, and derived metamorphic rocks

36 Alkaline Plutonic Rocks
Nepheline and alkaline syenites, fenite, associated mafic, ultramafic and carbonatitic rocks

35 Early Felsic Plutonic Rocks
Granodiorite, trondhjemite, monzo and syenogranites, derived gneisses and migmatites

Metasediments
Grenville Supergroup and Flinton Group[c]

34 Carbonate Metasediments
Marble, calc–silicate rocks, skarn

33 Clastic Metasediments
Conglomerate, greywacke, quartz arenite, arkose, siltstone, chert, minor iron formation and metavolcanics

32 Metavolcanics
Mafic to Felsic Metavolcanics
Flows, tuff, breccia, minor iron formation and metasediments. Includes reworked pyroclastic units.

MIDDLE PROTEROZOIC

Central Gneiss Belt

31 Felsic Igneous Rocks
Granodiorite, monzonite, granite, syenite, derived gneisses

30 Alkaline Igneous Rocks
Nepheline and alkaline syenites

29 Anorthositic Rocks
Anorthosite, gabbro and derived gneisses

28 Mafic Igneous Rocks
Amphibolite, gabbro, tonalite, diorite, derived gneisses and migmatites

27 Metasediments
Marble, marble breccia, quartzite, quartzofeldspathic gneiss of metasedimentary origin?

SUPERIOR AND SOUTHERN PROVINCES

LATE PROTEROZOIC

26 Post Keweenawan Sediments
Jacobsville and Oronto Groups
Sandstone, shale, conglomerate

MIDDLE PROTEROZOIC

25 Keweenawan Volcanic and Sedimentary Rocks
Basalt, rhyolite tuff, quartz porphyry, conglomerate and arkose

24 Mafic and related Intrusive Rocks
Gabbro, diabase and granophyre (Logan Type)

23 Sibley Group Sediments
Conglomerate, sandstone, shale, carbonate rocks

TABLE 2.1. CONTINUED.

EARLY PROTEROZOIC		
22	Sudbury Igneous Complex	Norite, gabbro, and granophyre
21	Animikie Group[d]	Greywacke, shale, iron formation, limestone, argillite
20	Whitewater Group[e]	Fragmental rocks, mudstone, wacke
19	Mafic and Related Intrusive Rocks	Gabbro, diabase (Nipissing type)
18	Huronian Supergroup Cobalt Group[f]	Conglomerate, greywacke, quartz arenite, siltstone, argillite
17	Huronian Supergroup Elliot Lake, Hough Lake, andQuirke Lake Groups	Conglomerate, greywacke, arkose, quartz arenite argillite, limestone, dolomite, basalt
16	Huronian Metavolcanics (Elliot Lake Group)	Basalt, rhyolite
15	Mafic and Ultramafic Intrusive Rocks	Gabbro, anorthositic gabbro, and anorthosites
ARCHEAN		
SUPERIOR PROVINCE		
MIDDLE TO LATE ARCHEAN		
14	Diorite-nepheline Syenite Suite[c]	Pyroxenite-diorite-monzonite-syenite-nepheline syenite (saturated to undersaturated suite)
13	Massive Granodiorite to Granite	Massive to foliated granodiorite to granite
12	Diorite-monzonite-granodiorite Suite[c]	Diorite-tonalite-monzonite-granodiorite-syenite and hypabyssal equivalents (saturated to oversaturated suite)
11	Muscovite-bearing Granitic Rocks[c]	Two mica granite, granodiorite-tonalite
10	Foliated Tonalite Suite[c]	Foliated to massive tonalite-granodiorite
9	Gneissic Tonalite Suite[c]	Gneissic to foliated tonalite-granodiorite with minor supracrustal inclusions
8	Mafic and Ultramafic Rocks[c]	Gabbro, anorthosite, and ultramafic rocks
Late Metavolcanics and Metasediments[g]		
7	Clastic Metasediments	Coarse to fine clastic metasediments, with minor mafic to felsic (flows, tuffs and breccias) metavolcanics (saturated to undersaturated)
Metavolcanics and Metasediments[c]		
6	Migmatized Supracrustal Rocks	Mainly metavolcanics and minor metasediments with minor granitic gneisses
5	Metasediments	Wacke, arkose, argillite, slate, conglomerate, marble, chert, iron formation, derived migmatites, and minor volcanics
Metavolcanics		
4	Felsic to Intermediate Metavolcanics	Rhyolite, rhyodacite, dacite and andesite (flows, tuffs and breccias) chert, iron formation, minor metasediments and intrusiverocks, and related migmatites; selected alkalic mafic to felsic metavolcanics
3	Mafic Metavolcanics	Basalt, andesite (flows, tuffs and breccias) chert, iron formation, minor metasediments and intrusive rocks, and related migmatites
2	Ultramafic Metavolcanics	Komatiite-bearing mafic metavolcanics, minor metasediments and pyroclastics
1	Clastic Metasediments and Mafic Metavolcanics	Quartz arenite, coarse clastic metasediments, iron formation, komatiite, mafic metavolcanics, minor felsic metavolcanics and marble

NOTES

a) May be in part post-Precambrian.

b) A generalized distribution of diabase dikes is shown.

c) Rocks in these groups are subdivided lithologically. The order does not imply age relationship within or among groups.

d) Includes Gunflint and Rove formations.

e) Includes Chelmsford, Onwatin, and Onaping formations.

f) Includes Gowganda, Lorrain, Gordon Lake, Bar River formations.

g) Formerly classified as Timiskaming.

2. "Timiskaming" type sequences consist of fluviatile to shallow marine sediments and alkalic to calcalkalic volcanics deposited in fault–bounded basins spatially associated with large–scale shear zones (Stott 1986; Poulsen 1984; Thurston and Chivers, in press), and are shown in the legend as unit 7. The fact that these basins developed after the early deformation of greenstone belts and during the second deformation related to the horizontal movement along subprovince boundaries has lead to them being compared to pull–apart basins in the modern environment (Stott 1986; Poulsen 1984).

Mafic sequences and mafic to felsic cyclical volcanism are the other two greenstone sequences described by Thurston and Chivers (in press), however, they do not form distinct lithologic packages that can be defined (separated?) by this legend.

Each of the above greenstone belt types displays distinct metallogenic patterns which will be dealt with more thoroughly on the metallogenic map. However, the newly defined platform sequence at Sakami Lake contains detrital uranium and gold (Roscoe and Donaldson 1988), and iron formations are found at Steeprock Lake (Joliffe 1955) and North Spirit Lake (Wood 1980).

GRANITOIDS

Since the most recent edition of the geological map of Ontario was produced (Ayres *et al.* 1971), the 1 inch to 4 mile reconnaissance of the Province has been completed. This work outlined all major greenstone belts and allowed for the additional subdivision of granitic rocks of the Superior Province. Granitoid rocks of both plutonic and granite–greenstone subprovinces have been subdivided into four major units as follows: (a) Gneissic Tonalite Suite; (b) Foliated Tonalite Suite; (c) Diorite–Monzonite–Granodiorite Suite; and (d) Massive Granodiorite to Granite (units 9, 10, 12, and 13, respectively, Table 2.1). These units are supplemented by muscovite–bearing granitic rocks and mafic and ultramafic intrusions (units 11 and 8, Table 2.1). The above major units may allow subdivision, upon completion of additional mapping and geochronology, into pre–greenstone units versus syn– to post–kinematic units. The recognition of these packages of granitic rocks will permit the identification of blocks of pre–greenstone crust and gneissic subprovinces, such as the Winnipeg River gneisses. Recognition of these packages of older granitic rocks will aid in the identification of granitic rocks with high mineral potential, for example, the mineralized portion of the Marmion tonalite (Patterson *et al.* 1986).

In a sample area shown in Figure 2.1, the new granitoid legend has been used with some geochronology, mapping of limited areas (Breaks *et al.* 1985), and field checking of the subdivision this field season, to provide an improved understanding of the area. The new interpretation allows separation of the anomalously auriferous muscovite–bearing

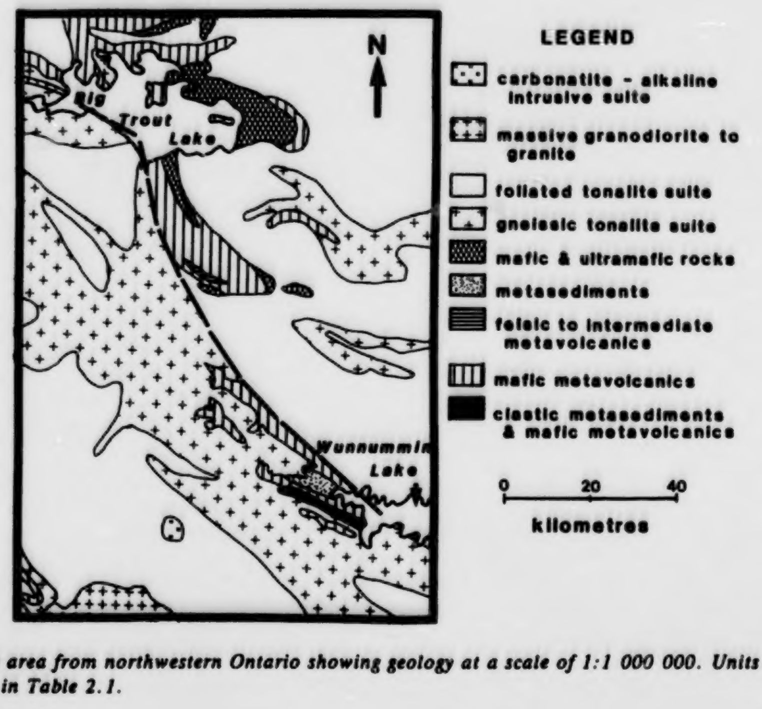

Figure 2.1. *Sample area from northwestern Ontario showing geology at a scale of 1:1 000 000. Units correspond to those in the legend shown in Table 2.1.*

granites, and distinction of the post–tectonic granitoids which host uranium mineralization.

SEDIMENTARY SUBPROVINCES

The previous edition of the provincial geological map (Ayres *et al.* 1971) showed the sedimentary subprovinces of the Superior Province (English River and Quetico subprovinces) in a general fashion. Mapping programs since then (summarized by Breaks *et al.* 1978; Percival and Williams 1988) have demonstrated that:

1. These subprovinces consist of large expanses of wackes in the central part of the subprovinces, with some conglomeratic units on the northern margins of both Quetico and English River subprovinces.
2. The Quetico Subprovince continues across the Ontario part of the Superior Province from the Minnesota border to the Quebec border.
3. The southern contact of the Quetico Subprovince with the Abitibi Subprovince is a major shear zone marked by the presence of fault–bounded slices of mafic metavolcanics and intrusions.
4. The Quetico Subprovince is separated from the Wabigoon Subprovince in the Beardmore–Geraldton area by a series of major east–trending strike–parallel shear zones.
5. The English River Subprovince as defined by Ayres *et al.* (1971) consists of a southern gneissic part, the Winnipeg River Subprovince (largely gneissic), and a northern part, the English River Subprovince, largely wackes (cf. Card and Ciesielski 1986).
6. The sedimentary subprovinces have been interpreted (Williams, this volume) as accretionary prisms of deep water sediments formed south of the Wabigoon and Uchi subprovinces, respectively.

STRUCTURAL/TECTONIC STUDIES

Reinterpretation of large parts of the Superior Province using aeromagnetic data and remote sensing images has resulted in the recognition of several new major shear zones (Osmani and Stott, this volume; Mussakowski and Trowell, this volume). These observations coupled with gold–related structural studies (Stott and Smith 1988), indicate that many additional major shear zones should appear on this edition of the provincial map. Some of these newly delineated shear zones crosscut the Uchi–Sachigo Subprovince boundary, suggesting that modifications are also necessary to subprovince boundaries and nomenclature.

Contact strain aureoles are in some cases significant enough to display at the 1:1 000 000 scale, particularly in parts of the Uchi Subprovince. The subprovince–bounding shear zones produced during late transpression events young irregularly southward from the southern boundary of the Uchi Subprovince (Stott *et al.* 1987). This sort of situation is readily interpretable in terms of an accretionary tectonic scenario.

Implied in the above observations and modifications are major changes in the complexion of the provincial map. The Abitibi and parts of the eastern (cf. Blackburn and Johns, this volume) and western Wabigoon Subprovince may represent separate terranes within the overall framework of the Wabigoon Subprovince as classically defined. Similar subdivisions of the Uchi and Abitibi subprovinces are envisioned. In fact, Marmont and Corfu (in press) show that the age of the last deformation in the Detour Mine area in the external zone of the Abitibi Subprovince is about 2720 Ma, whereas the last deformation in the internal zone is less than 2700 Ma. From this, it is concluded that part of the external zone, i.e. the Detour Lake belt, probably represents part of the Wabigoon Subprovince, rather than the Abitibi.

In summary, major changes in the shape of individual greenstone belts, the level of detail displayed in granitoid areas, and the character and extent of individual subprovinces will make this synthesis a worthwhile update.

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Northwestern Ontario

3. Northwestern Superior Province

P.C. Thurston and G.M. Stott

Geologists, Precambrian Geology Section, Ontario Geological Survey, Toronto.

INTRODUCTION

The northwestern Superior Province constitutes approximately one third of the exposed Archean crust in Ontario. While selected areas are covered by recent detailed mapping, much of the area is covered only by reconnaissance mapping carried out 20 years ago. The relative expense of working in areas which lack road access, in part, accounts for the somewhat low level of both geological survey and exploration coverage. In planning further work in this area, it was considered necessary to re–evaluate our knowledge of its geological framework. This re–evaluation is coincident with the current revision of the 1:1 000 000 scale geological map of Ontario. The work reported in this section is not only directly relevant to re–evaluating the exploration potential of the area, but also is important to rational planning of future mapping projects.

It is now apparent that gold mineralization is localized by linear composite shear systems or deformation zones. As regional scale linear features, they are not amenable to documentation by traditional township mapping. Several projects were designed to conduct selective or comprehensive mapping along their length. This work has identified previously unrecognized deformation zones as well as having provided better definition of others. Consequently, this work will assist in targeting favourable areas for gold mineralization.

This work is of further practical importance. These deformation zones commonly form the boundaries between subprovinces which are characterized by entirely different packages of rocks. Subprovinces constitute metallogenetic domains with potential for different styles of mineral deposits. This year's work has significantly revised the interpretations of the distribution of subprovinces in northwestern Ontario.

Within subprovinces, mapping focused on detailed coverage of greenstone sequences and regional coverage of granitic sequences. Thurston *et al.* (1987) described the widespread occurrence of platformal greenstone sequences in the Sachigo Subprovince. We now recognize four principal greenstone types, each with its own characteristic metallogenetic association (Thurston and Chivers, in press). Detailed mapping has now better defined this subdivision in several belts and has allowed prioritization of additional areas for further mapping.

Over large areas of the northwest, predominantly granitic and gneissic terranes have been generally grouped together. It is clear now that they constitute composite terranes with a variety of ages and compositions of plutons which can be distinguished by regional mapping. This work is being incorporated in the new geological map of Ontario. This work provides the basis for assessing mineral potential and underlines the need for further map-

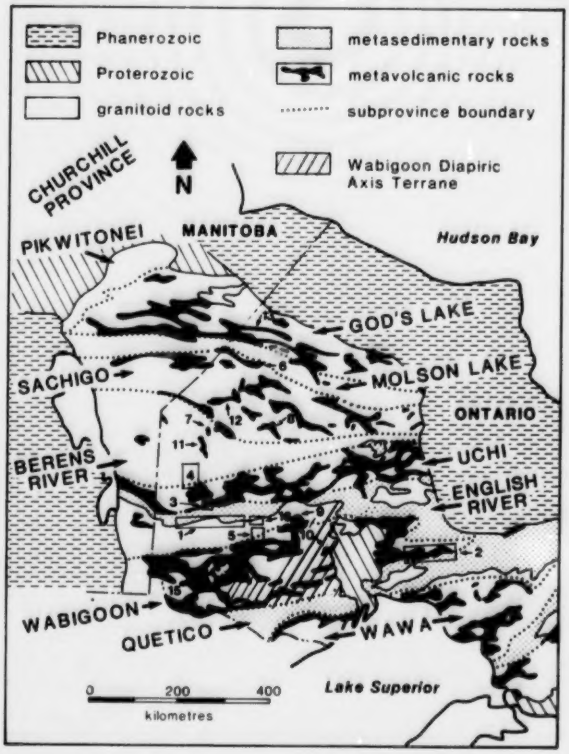

Figure 3.1. *Location Map of areas studied this past summer. 1. Winnipeg River Subprovince–English River Subprovince boundary 2. Quetico Subprovince–Wabigoon Subprovince boundary 3. Uchi Subprovince–English River Subprovince boundary 4. Berens Subprovince–Uchi Subprovince boundary 5. Wabigoon Subprovince–Winnipeg River Subprovince boundary 6. Pierce Lake–Ponash Lake–Sachigo Lake Greenstone Belt 7. Hornby Lake Greenstone Belt 8. Upper Windigo Lake greenstone belt 9. Savant Lake Greenstone Belt 10. Obonga Lake Greenstone Belt 11. McInnes Lake greenstone belt 12. Sandy Lake greenstone belt 13. Blackbear River–Ellard Lake Greenstone Belt 14. Atikwa–Lawrence Lake batholith 15. Aulneau batholith 16. English River–Winnipeg River transect*

ping coverage. In addition, the improved understanding of pluton evolution assists in the re-appraisal of the tectonic framework of the Superior Province.

SUBPROVINCE BOUNDARY RELATIONSHIPS

Subprovince boundaries are delineated by lithological, metamorphic, or structural discontinuities. They are often marked by the development of regional scale dextral shear zones. Some represent a shift in PT conditions from the greenschist to subgreenschist conditions of granite–greenstone subprovinces to the amphibolite to granulite conditions of sedimentary and gneissic subprovinces. The major shears themselves and secondary splays are a major control on the locus of Archean lode gold deposits (Colvine *et al.* 1988). Therefore, in an effort to accurately locate the major subprovince boundaries and assess their mineral potential, projects were established to examine the following areas:

1. The English River–Winnipeg River Subprovince boundary (Sanborn–Barrie, this volume) (Figure 3.1) has been known as a prominent lithologic boundary between metasediments of the English River Subprovince and intrusive, gneissic, and granitoid rocks of the Winnipeg River Subprovince, but was not previously identified as a structural discontinuity (Breaks *et al.* 1978; Beakhouse 1985). The present project has shown that the boundary is a major deformation zone which apparently extends for several hundred kilometres. Along its length, metamorphic and structural styles vary. Amphibolite facies conditions with steep dips prevail in the west at Separation Lake, while areas of recumbent folding subjected to granulite facies conditions are found at the eastern part of Lac Seul. The presence of the remains of the Separation Lake Greenstone Belt through the length of the shear zone suggests the Winnipeg River Subprovince may be a deep level granite–greenstone subprovince rather than a plutonic terrane. As well, the Bird River granite–greenstone subprovince of Card and Ciesielski (1986) may be a higher erosional level of the Winnipeg River Subprovince.
2. The Quetico–Wabigoon Subprovince boundary in the eastern Wabigoon Subprovince at Beardmore–Geraldton (Figure 3.1) has been the object of a structural–metallogenic study (cf. Williams 1987). This work, in addition to identifying major controls of gold mineralization associated with the major shear system separating the two subprovinces, has resulted in the development of a new tectonic model for the Quetico Subprovince as an accretionary prism (Percival and Williams, in press).
3. The boundary between the Uchi Subprovince and the English River Subprovince (Figure 3.1) to the south is the locus of the Sydney Lake–Lake St. Joseph Fault Zone first described by Stone (1981); the zone extends from Lake Winnipeg through to Lake St. Joseph (Stott 1985). Reconnaissance examination of this feature revealed a similar structural regime to that developed for the Winnipeg River–English River boundary. This regime comprises moderately to vertically plunging lineations on steep fabrics in domain one, which, in a second domain, are rotated to shallower plunging attitudes by later deformation along the shear zone. Again, the structures and lithologies suggest juxtaposition late in the deformation history of the sedimentary terrane against the Uchi Subprovince.
4. The Berens Subprovince (Card and Ciesielski 1986) is a plutonic subprovince north of the Uchi granite–greenstone Subprovince. Investigations by Stone (this volume) and Cortis *et al.* (this volume) suggest that there is no conventional shear zone boundary between these two domains (Figure 3.1). The distribution of metamorphic grade and structures and geometry of the plutonic rocks suggests that the Berens Subprovince may represent a deeper crustal level of a granite–greenstone subprovince. The north-trending stratigraphy and elongation of plutons is most directly related to the trend of the Sachigo and northern Uchi Subprovince greenstone belts.
5. The Wabigoon–Winnipeg River Subprovince boundary (Figure 3.1) zone was examined in the area of Sioux Lookout (Beakhouse, this volume) where out-of-sequence stratigraphy and the heterogeneous distribution of strain within supracrustal sequences suggests this boundary zone includes allochthonous stratigraphy.

GREENSTONE BELTS

In last year's volume, Thurston and co-workers (1987) described a new type of greenstone sequence containing basal quartz arenites overlain by iron formation and komatiites which are compared to modern shallow water platform sequences. These sequences occur in every major greenstone belt in Sachigo Subprovince leading to the suggestion that the Sachigo Subprovince forms a sialic nucleus around which the subprovinces to the south accumulated. The platform sequences are older than the mafic to felsic cyclical volcanics and contain a completely different assemblage of mineralization (Thurston and Chivers, in press). The quartz arenites have potential for detrital uranium and gold (Roscoe and Donaldson 1988), the iron formations contain iron and potential manganese deposits (e.g. Steeprock Lake (Joliffe 1955)), and the overlying volcanics have potential for volcanogenic nickel deposits (Naldrett and Gasparrini 1971). Therefore, several greenstone belts which have not been mapped recently were examined in the search for possible platform sequences (Cortis *et al.*, this volume) in order to

1. develop stratigraphic models for complex belts (e.g. Savant Lake–Thurston *et al.* 1987)
2. locate possible older greenstone belts given the >2.85 Ga age of all dated platform sequences (Thurston and Chivers, in press)
3. ascertain whether the Berens Subprovince is distinct from the Uchi and Sachigo subprovinces in terms of greenstone stratigraphy

The results of these studies are as follows:

1. Quartz arenite bearing platform sequences were found at Sachigo Lake and Hornby Lake in the Sachigo and Berens subprovinces respectively (Figure 3.1).
2. A quartz arenite and conglomerate–bearing red bed sequence indicative of subaerial oxidizing conditions was found in the Jutten Group, the lower stratigraphic unit of the Savant Lake Greenstone Belt (Trowell 1986) (Figure 3.1).
3. In the Obonga Greenstone Belt (Thurston 1967) south of Armstrong within the Wabigoon Diapiric Axis (Thurston and Davis 1985) (Figure 3.1), an unconformity between the basal basaltic flows of the greenstone belt and the underlying granitoid rocks was discovered. By comparison with the Steeprock Group within the Wabigoon Diapiric Axis, which lies unconformably upon ~3 Ga granitoids (Davis and Jackson 1988), there is a possibility this sequence is older than 2.7 Ga.
4. The McInnes Lake Greenstone Belt (Figure 3.1) was remapped by Cortis *et al.* (this volume). While platform sequences were not recognized, the mapping showed that the belt consists of three mafic to felsic volcanic cycles. The volume of rhyolitic material and coarse nature of the pyroclastics suggests possible base–metal mineralization potential.
5. Reconnaissance of the Swan Lake and Blackbear River–Ellard Lake greenstone belts (Figure 3.1) revealed basaltic and minor rhyolitic metavolcanics with no platformal association (Osmani and Stott, this volume). The belts are complexly folded and are cut by shearing, related to the southeast–trending Kenyon Structure (Wilson 1971), and the Stull Lake – Wunnummin Lake Fault Zone at Swan Lake (Osmani and Stott, this volume).

Several conclusions can be drawn from the greenstone investigations:

1. Platform sequence greenstones prevail in the Sachigo, Berens, and Wabigoon Diapiric Axis suggesting these areas represent older blocks and may all represent independent subprovinces.
2. The northerly trend of plutonic units and greenstone remnants in the Berens Subprovince and northern part of the Uchi Subprovince and the lack of a discrete shear boundary between the Berens and Uchi subprovinces suggests the Berens Subprovince may simply be a deeper crustal level of a granite–greenstone subprovince. Substantial revisions to subprovince boundaries may be required.
3. The prevalence of platform sequences with an entirely different metallogeny suggests exploration ought to concentrate on platform sequence deposit types: gold, uranium, tungsten, barium, boron, iron, manganese, and nickel. The indicated older age of these sequences suggests more than one age of shear–related gold deposits may be present. If so, the later shear zones may transect old granitoid units as well as supracrustals.
4. The coarse rhyolitic pyroclastics in the McInnes Lake Greenstone Belt may have volcanogenic massive sulphide potential.

GRANITOID ROCKS

Granitic rocks in Precambrian shields throughout the world consist of pretectonic gneissic and foliated tonalites succeeded by syntectonic to posttectonic tonalites to monzonites and finally posttectonic potassic granitoids. Field relations in the Superior Province are consistent with this pattern. We are generally able to erect a field–based chronology of granitoid rocks, but we cannot at this time substantiate this progression with chemical and geochronologic data. We are attempting to provide this type of documentation for granitoids in granite–greenstone subprovinces, plutonic subprovinces, and sedimentary subprovinces. To facilitate this, Beakhouse (this volume) concentrated upon the Atikwa–Lawrence and Aulneau batholiths (Figure 3.1) in the Western Wabigoon Subprovince and the granitoids of part of the Winnipeg River Subprovince. Breaks (this volume) examined a transect through the English River and Winnipeg River subprovinces (Figure 3.1) which included granitoid rocks of gneissic and metasedimentary terranes.

In metasedimentary subprovinces particularly, the succession of granitoid types is well established (Breaks *et al.* 1978), but we cannot relate intrusive events to the chronology of metamorphic events which give rise to peraluminous granites. Breaks describes multiple metamorphic pulses and three episodes of emplacement of peraluminous S–type granites within the English River Subprovince. These granites occur at a variety of crustal levels from catazonal to mesozonal. Anomalous background gold concentrations have been observed within S–type granites in a metasedimentary gneiss in Sachigo Subprovince (Breaks *et al.* 1986). Therefore, given the anomalous gold environment and the demonstrated rare metal and uranium potential of this suite (Breaks *et al.* 1978), it is important to know which generation of granite is most likely to be mineralized and which crustal level is most favourable.

Within the granite–greenstone subprovinces, the following new observations were made:

1. Early granitoid units in the Wabigoon Diapiric Axis, such as the Marmion complex (Davis and Jackson 1988), are more extensive than believed previously. Given the gold association with this rock type (Patterson *et al.* 1986), follow up work on any potential shear zones within tonalites in areas such as at Upsala (Beakhouse, this volume) may be warranted.
2. Magma mixing textures are associated with platinum group element deposits at Lac des Iles (Sutcliffe 1986). These textures have been noted in the Atikwa–Lawrence batholith (Davis and Edwards 1985; Beakhouse, this volume). Therefore, gabbroic bodies related to large late granitoid complexes in the western Wabigoon Subprovince have potential for this type of mineralization.

The ages of granitoids in the Winnipeg River Subprovince do not correspond with known ages of volcanism or plutonism in the Uchi and Wabigoon subprovinces save for the latest episodes (Corfu 1988). The oldest unit, a gneissic tonalite 3170 Ma in age in the Cedar Lake Dome, contains inclusions of metavolcanics. Therefore, the oldest lithologies in this subprovince have not yet been delineated. In fact, Breaks (this volume) indicates that the Deception Bay Gneissic Complex may be older than the dated 3 Ga gneisses (Krogh *et al.* 1976) at Sen Bay. Given the competence of tonalitic rocks, identification of old tonalites is critical from evolutionary and metallogenic perspectives. The old tonalites form an excellent host for shear-related lode gold, e.g. the 3 Ga Marmion Lake Batholith (Patterson *et al.* 1986). Therefore, development of methods for identification of large blocks of old granitoids is useful in pointing toward areas worthy of exploration attention. As well, knowledge of age relationships in tonalitic areas will lead to recognition of any shear systems through identification of discontinuities in age and rock type.

These studies must also address whether specific ages of granitoids at particular crustal levels are prospective for given styles of mineralization such as high-level plutons within greenstones for porphyry copper–molybdenum.

SHEAR ZONES

In addition to subprovince boundaries, shear zones occur in the following settings:

1. as major boundaries within greenstone belts, e.g. the Kirkland–Larder Lake Break
2. near pluton boundaries as a result of contact strain during pluton emplacement or collisional events (Stott and Smith 1988)
3. as late sigmoidal structures transecting the Uchi, Berens, and Sachigo subprovinces described by Osmani and Stott (this volume)

All of the above shear zone types control gold mineralization in various parts of the Superior Province. However, the last type of shear zone is most important because this type is quite large and relatively unexplored. Examples of deposits hosted by sigmoidal shear zones are the Golden Patricia Deposit and the Sachigo River Mine, which provide ample demonstration of the importance of these late shear zones as a structural type controlling a new class of gold deposits.

Shear zones corresponding to major tectonic boundaries between subprovinces are probably the most important type of shears from both an evolutionary and metallogenic standpoint. These structures separate blocks with different metallogeny, lithology, and age. The shear zones represent varying ages of development (Stott *et al.* 1987), younging more or less systematically southward across the Superior Province. Subdivision of the shield on a geochronological basis will allow better overall understanding resulting in some ability to do predictive metallogenic work.

SUBPROVINCIAL SUBDIVISION OF SUPERIOR PROVINCE

The programs described in the following section of this volume have brought about several changes in the large scale subdivision of the Superior Province. The follow-up work on platform sequences and reconnaissance of the Berens Subprovince have suggested the Berens Subprovince may not be a conventional fault-bounded subprovince with distinct lithologies, structures, and distribution of ages. The Winnipeg River Subprovince may be more appropriately considered as a granite–greenstone terrane in that no southern tectonic boundary to the Separation Lake Greenstone Belt has been found, which should be the case if the belt is part of the fault-bounded Bird River Subprovince. This brings into question the independent existence of the Bird River Subprovince of Card and Ciesielski (1986).

SUMMARY

This group of projects has identified new lithostratigraphic associations in the greenstone environment with distinctive metallogeny. Future work will involve seeking indications of tungsten, boron, and barium mineralization in platform sequences.

The granitoid work will allow characterization of plutonism in granite–greenstone and gneissic blocks.

The concentration upon subprovince boundaries will lead toward a terrane-based analysis of the Superior Province. The major blocks will be subdivided into a variety of terrane types now that distinct greenstone and sedimentary belt environments have been identified. Assessment of the scale of the strain pattern over large greenstone belts will provide a clearer picture of the association of the late deformation with major shear zones. An irregular southward younging of the second deformation has been proposed (Stott *et al.* 1987). Upon completion of terrane analysis, this age progression will perhaps permit discussion of the Superior Province assembly in terms of terrane amalgamation and major collision of subprovinces. This is of critical importance in gold metallogeny for it may disclose the presence of multiple gold mineralizing events.

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4. Project Number 88–10. Geology of the Keewaywin Supracrustal Sequence; Sandy Lake Greenstone Belt, Northwestern Ontario

A.L. Cortis

Graduate Student, University of Manitoba, Winnipeg, Manitoba.

INTRODUCTION

This project was designed to assess the depositional environment of an Archean platform sequence in order to assess the potential for mineralization similar to that found in Proterozoic platforms. The project represents a follow–up to a reconnaissance survey in 1987 (Thurston *et al.* 1987). Work was concentrated on the Keewaywin platformal sequence at the east end of Sandy Lake. Platformal sequences consisting of a quartzite–carbonate–iron formation–komatiite association and dated at about 3.0 to 2.9 Ga have been identified in the lower parts of several greenstone belts in the Sachigo Subprovince (Wood *et al.* 1986; deKemp 1987; Wood and Thurston, in preparation; Thurston *et al.* 1987; Thurston and Chivers, in press). The platform sequences have important implications for Archean crustal evolution as they imply the existence of a stable craton prior to major greenstone volcanism at about 2.9 to 2.7 Ga (Ayres and Thurston 1985).

Platformal sequences have a distinctive metallogenic association (Thurston and Chivers, in press). Occurrences of detrital Au and U mineralization of similar style to younger cover sequences (e.g. the Witwatersrand and Huronian Supergroups) are reported from India (Srinivasan and Ojakangas 1986), Sakami Lake (Roscoe and Donaldson 1988) and Eyapamikama Lake (Thurston and Chivers, in press) in the Superior Province. Stratiform barite, scheelite and tungsten mineralization is also associated with such environments worldwide (Thurston and Chivers, in press).

Emphasis was placed on description and sampling of stratigraphic sections, and on definition of various facies associations.

LOCATION AND ACCESS

The Sandy Lake Greenstone Belt is 150 km north of Red Lake, Ontario at Latitude 53°00'N, between Longitudes 92°20'N and 93°40'N. The area of de-

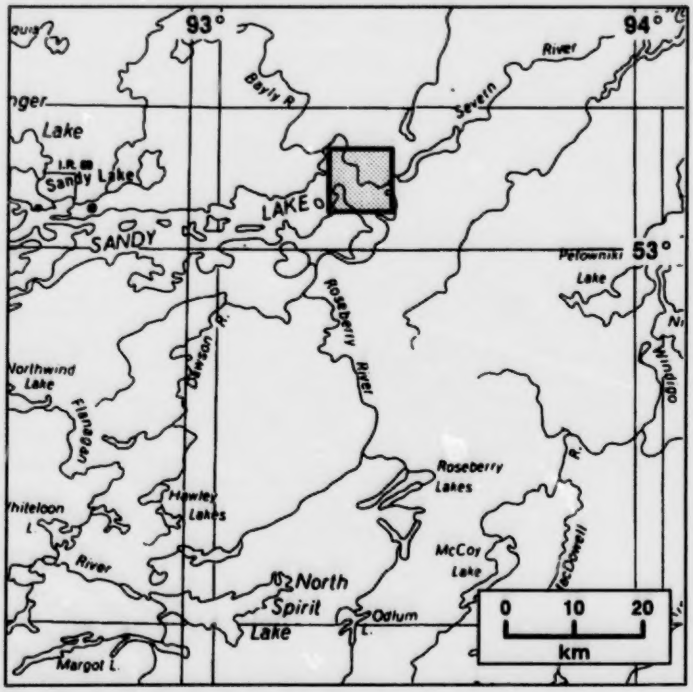
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Figure 4.1. *Location map for the Sandy Lake Greenstone Belt.*

tailed study is at the far eastern end of Sandy Lake and covers about 49 km² (Figure 4.1).

PREVIOUS WORK

The belt was mapped by Satterly (1938), and Bennet and Riley (1969). More recently, Thurston *et al.* (1987) made a brief reconnaissance to identify possible platformal sequences. Large areas of the belt have been staked by JVX Explorations and diamond drilling was carried out during the last two winters. Results of this exploration program are unknown, but exploration is continuing.

REGIONAL GEOLOGY

Rocks of the Sandy Lake area are of Archean age and consist of a granite–greenstone assemblage typical of the Sachigo Subprovince (Ayres and Thurston 1985). The belt is divisible into several distinct supracrustal units bounded by late granitoid bodies (Thurston *et al.* 1987).

NORTH SHORE SEQUENCE

The North Shore Sequence of mafic flows and felsic pyroclastic rocks extends from the northwest arm of Sandy Lake along the north shore to Harper Bay. Uniform younging directions in mafic flows and interflow sediments suggest that the North Shore Sequence is a south–younging homocline (Thurston *et al.* 1987). Within the study area the sequence swings from the easterly trend characteristic of most of the belt to a northeasterly trend.

Pillowed mafic flows thin from 30 to 100 m thick west of the area to 1 to 20 m within the area and are capped by thin oxide and silicate facies iron formation. Interspersed with the mafic flows are discontinuous pillowed ultramafic to mafic flows and thin–bedded iron formation and ultramafic tuff. These are dark green and contain a talc–actinolite–chlorite or tremolite–chlorite assemblage. Tuffaceous units are interbedded with oxide facies iron formation.

West of Fishtail Bay, the basal mafic volcanic rocks of the North Shore Sequence are overlain by felsic to intermediate pyroclastic rocks. These pyroclastic rocks were erupted at least partially in a subaerial setting (Thurston *et al.* 1987). Felsic pyroclastic rocks are absent east of Fishtail Bay but a 100 to 200 m thick unit of intermediate tuffs and oxide–facies iron formation occurs within mafic flows in the northern part of the study area (Figure 4.2). Within mafic flows north of the Keewaywin Sequence, graded felsic ash indicate the volcanic rocks here are northeast facing.

The top of the North Shore Sequence is marked by oxide and silicate facies iron formation. The main part of the North Shore Sequence is separated from the Keewaywin clastic sedimentary sequence by a northeast–trending, dextral shear zone. In this area, the upper iron formation–rich top of the North Shore Sequence is absent.

GRANITOIDS

South of the supracrustal sequence, a large, late potassic feldspar megacrystic granodioritic to monzogranite body, the Niska Pluton, was traced along the south shore of Sandy Lake from Niska Lake to the eastern end of Sandy Lake (*see* Figure 4.2). The body is inequigranular and inhomogeneous, and cut by layer–parallel pegmatite and aplite dikes with pervasive potassic alteration. Alteration varies from being confined to the proximity of the dikes to pervasive. The Niska Pluton is internally massive, but has a marked contact strain aureole.

On the east margin of the belt, the supracrustal rocks are in sheared contact with a tonalitic to granodioritic gneissic body of the Rottenfish Pluton (*see* Figure 4.2). Near the supracrustal contact, the gneiss is fine– to medium–grained, inhomogeneous and equigranular. Gneissic banding is well developed. This body exhibits potassic feldspar megacryst development around aplite dikes. The southeast–trending contact between the Rottenfish gneiss and the supracrustal rocks is dextrally sheared with chlorite alteration along shear planes. The relationship between the Rottenfish and the Niska Plutons is uncertain. However, gneissic fabric in the supracrustal rocks is truncated and overprinted by shear fabric related to the Niska Pluton, indicating the Rottenfish Pluton was emplaced prior to the Niska Pluton.

KEEWAYWIN SEQUENCE

Exposures of the Keewaywin sedimentary sequence are restricted to islands in Harper Bay and the adjoining mainland. Vertical and lateral changes in lithology indicate that the entire sequence represents an upward coarsening megacycle suggesting progradation of a fan delta into a basin modified by deformational events.

A north to south transition along strike from conglomerate and sandstone dominated, to mud and iron formation dominated sediments reflects a proximal to distal transition in depositional setting. Based on lithological assemblages, primary structures, and spatial relationships, rocks of the Keewaywin Sequence are divided into four distinct associations (*see* Figure 4.2):

1. Proximal association: Northern east mainland and island #1.
2. Medial association: Southern east mainland and islands #2 to #4.
3. Distal association: Southern east mainland and islands #4 to #7.
4. Deep Basinal association: South mainland and islands #5 to #7.

PROXIMAL SETTING

The northernmost part of the Keewaywin Sequence on the east mainland and island #1 consists of quartzite, conglomerate, slump deposits (Walker 1984) and plane–bedded sheet sandstones. There is a marked absence of mud. Bed contacts of slump deposits and most sandstones are commonly amalgamated (Walker 1978). On island #1, slump deposits characterized by chaotically sorted blocks of quartz–

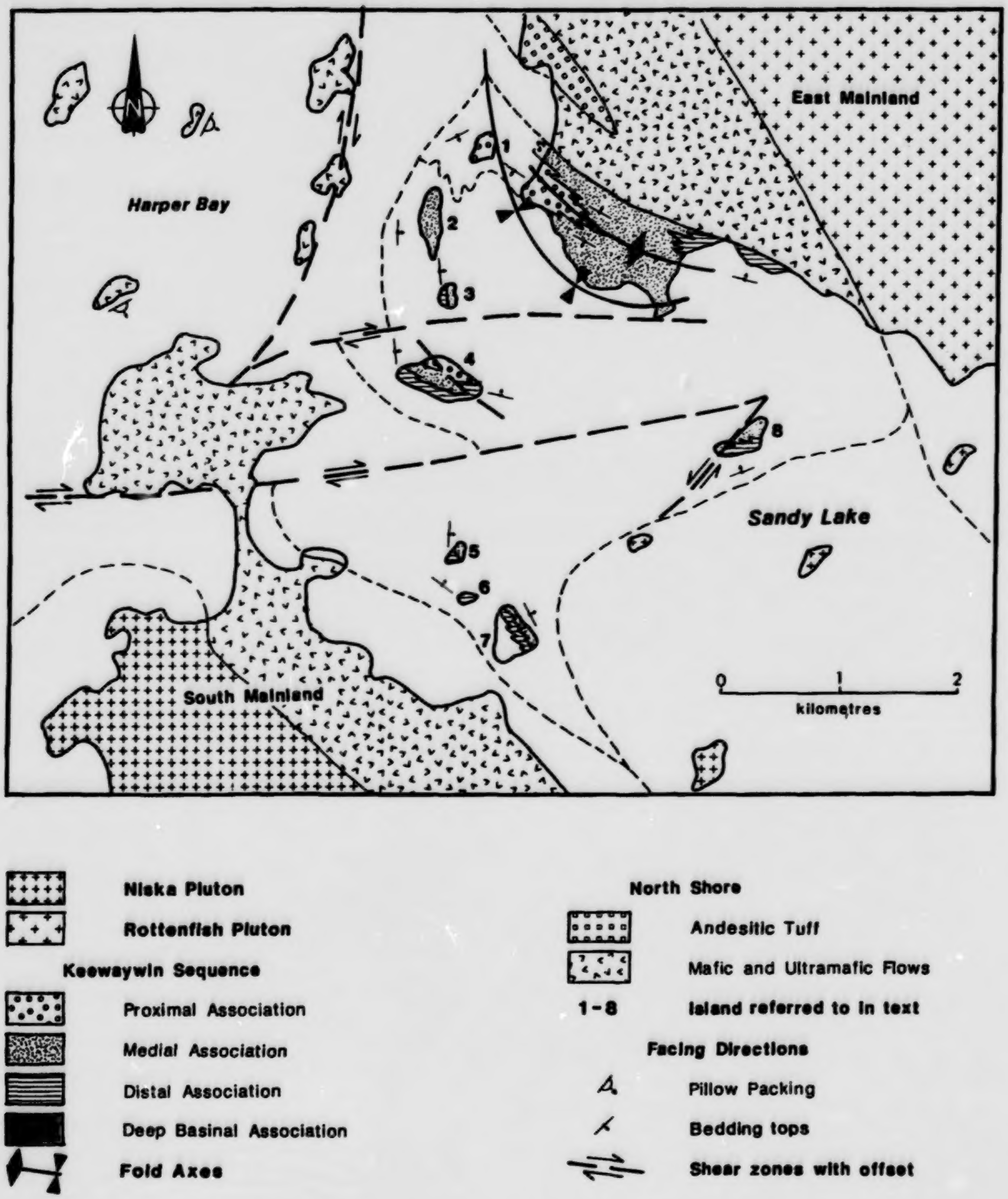
N
East Mainland
Harper Bay
1
2
3
4
8
Sandy Lake
5
6
7
South Mainland
0
1
2
kilometres
Niska Pluton
Rottenfish Pluton
Keewaywin Sequence
Proximal Association
Medial Association
Distal Association
Deep Basinal Association
Fold Axes
North Shore
Andesitic Tuff
Mafic and Ultramafic Flows
1-8
Island referred to in text
Facing Directions
Pillow Packing
Bedding tops
Shear zones with offset

Figure 4.2. *General geology of the Keewaywin Sedimentary Sequence showing the four distinct associations, adjacent granitoids and supracrustal rocks. Numbers on diagram refer to islands discussed in the text.*

rich sediment supported by a quartz–arenite matrix form about 50 percent of the sequence. Massive sandstones with amalgamated beds form about 40 percent, and well defined sheet sandstones 10 percent. Conglomeratic units are locally present as coarse pebbly horizons in massive sandstones. In contrast, on the east mainland, late dikes occupy up to 60 percent of the rock and sediments only 40 percent. Slump deposits and sheet sandstones are absent.

Sandstones range from quartz–arenite to sublitharenite with lesser litharenites and feldspathic litharenites. Sand–sized lithic grains form at most 15 to 25 percent of the framework. Lithic clasts in the sandstones include: mudstone, aphyric and porphyritic felsic volcanics, chert and vein quartz. Rare, fine–grained plagioclase and chlorite–rich clasts of mafic metavolcanics are present. Framework grains are subrounded to subangular and poorly sorted. Grain size varies from granule to medium sand with rare pebbles and cobbles of vein quartz and chert. Grading is usually absent or only poorly developed. Three types of sandstone units are recognized:

1. quartzarenites associated with conglomerates
2. sheet sandstones associated with slump deposits
3. thick–bedded and massive sandstones

The most mature sands are quartzarenites associated with conglomerates on the east mainland. Quartzarenite sands are buff white and consist of framework quartz with <5 percent sericite matrix cement. Bedding thickness ranges from 10 to 100 cm but bedding planes are obscured by amalgamation and deformation. This deformation has resulted in local recrystallization. Beds of quartzarenite are associated with litharenites on the east mainland. These quartzarenites have a bimodal texture with two framework quartz populations: well rounded with high sphericity, and angular and immature. Although primary structures are absent, some quartzarenite beds associated with conglomerates contain a very subtle internal cleavage at about 10° to 30° to bed planes which may represent subtle cross beds. (L.D. Ayres, Professor, Department of Geology, University of Manitoba, personal communication, 1988).

Sheet sandstones are fine to medium sand with well–defined bed planes. Bedding thickness is usually 20 to 30 cm but may vary from 5 to 50 cm. Contacts are planar and scours largely absent. Typically, fine upper graded portions to beds are absent, although in one locality, beds repeatedly exhibit grading from coarse sand to silt. Usually sheet sandstones form discrete sets of beds up to 10 m thick separating thick slump deposits. However, rare individual thin sandstone beds can separate several metres of slump deposits or discrete conglomerate beds. Primary structures other than faint planar lamination are not observed in these sheet sandstones.

Thick–bedded and massive sandstone units form the bulk of the sandstones. They are distinguished from sheet sandstones by coarser grain size (coarse to granule sand) and amalgamation of most bed contacts. Average bed thickness is 60 to 70 cm. Sorting is poorly developed, therefore, top determination is difficult. Generally they tend to form monotonous units tens of metres thick. Rarely, a thick bed of very coarse sandstone is interbedded with sheet sandstones or conglomerates. Some beds exhibit a red staining of the matrix, usually toward the base, probably indicative of enrichment of iron–bearing detrital heavy minerals (L.D. Ayres, Professor, Department of Geology, University of Manitoba, personal communication, 1988).

Slump deposits are extremely thickly bedded, poorly sorted units in which clasts and blocks of quartz–rich sediment are supported by a quartzarenite matrix. These units occur randomly throughout the section on the northernmost island in the study area, but are not seen elsewhere. Commonly, slumps are laterally discontinuous and 2 to 30 m thick. As slump units may contain horizons with distinct clast sizes, the thicker slump units may represent amalgamation of several deposits. Clast types and the quartzarenite matrix of the slump deposits are similar to adjacent unslumped sandstones described above. The fragments are matrix–supported quartzwackes and quartzarenites, usually with <85 percent framework grains. The matrix of the fragments is a very fine–grained chlorite or carbonate–chlorite assemblage. The enclosing sandstone is >85 percent framework grains in a well–developed contact framework. This matrix difference reflects a primary difference in diagenetic processes and susceptibility to alteration.

Although conglomerates occur throughout the sedimentary sequence, only in the proximal setting do they form discrete units. Two types of conglomerate are recognized in the proximal setting;

1. conglomeratic sandstones
2. bedded conglomerates

1. Poorly sorted, pebble to cobble conglomeratic sandstones are intercalated with sheet sands and slump deposits on island #1. They form <1 percent of the sequence and are randomly distributed. Clast lithologies are identical to lithic components in the associated sandstones. They are distinguished from pebbly sandstones (Walker 1984) by the presence of >2 percent cobble–sized clasts and the lack of grading within the beds. Large clasts rarely exceed 10 percent of the rock. Beyond a coarser average grain size (very coarse granule sand), the sand–sized grains are identical to adjoining massive sandstones. The coarser grained nature of the conglomerates relative to the sandstones simply reflects a higher energy of deposition for these beds.

2. Bedded conglomerates are dominant, forming a >50 to <10 m wedge on the east mainland. The wedge lies within generally ungraded, medium– to

thick-bedded or amalgamated sandstones. Within the wedge, conglomerate beds are interbedded with supermature quartzarenites. On the outcrop scale, bedding is well developed, with thickness ranging from 0.5 to 2.0 m. Deformation and dikes prohibit tracing of beds laterally. The conglomerates are polymictic, poorly sorted and matrix supported. Beds contain 20 to 50 percent rounded to subrounded clasts of fine-grained sericite schist (30 to 60 percent), vein quartz (30 to 50 percent), laminated graphitic chert (10 to 20 percent), aphyric and porphyritic felsic volcanics (10 to 20 percent), oxide facies iron formation (5 to 7 percent), trondjhemite (1 to 2 percent) and quartzite (<1 percent). The proportions of clast types varies from bed to bed. The matrix is a supermature quartzarenite similar to the enclosing sandstones. Clast sizes range from granules to large cobbles and rare boulders. The unit is strongly deformed and recrystallized along with the enclosing sandstones. Less competent fragments are highly stretched, therefore, quantification of clast proportions is difficult. More competent clasts are relatively undeformed, exhibiting a high degree of rounding indicative of significant transport and reworking.

MEDIAL ASSOCIATION

About 200 to 300 m south of island #1, the proximal association grades laterally into a thick succession of sandstones, mudstones and siltstones. This association persists from islands #2 to #4 in Harper Bay, and from the central to southern east mainland (*see* Figure 4.2). A north to south transition is observed in which the sandstone : mudstone/siltstone ratio changes from about 6:1 on island #2, to about 1.3:1 on island #4. Within sedimentary rocks of the medial association, numerous fining or coarsening upward minicycles are seen. Fining upward cycles occur within channel fill sequences or as caps to massive pebbly sandstones. Coarsening up cycles usually precede onset of a channel scour or an abrupt increase in bed thickness. Channels and thick sandstone beds are no longer superimposed and wedge out laterally into thin laminated mudstones and sandstone-mudstone couplets of turbiditic origin (Figure 4.3).

The sands are litharenite to feldspathic litharenite and quartzarenites are largely absent. Although the lithic grains are identical to those seen in the proximal sandstones, they may form 40 to 50 percent of the rock. Mudstone intraclasts are the most common fragments followed by vein quartz and trondjhemite. In some localities, granitoid-derived clasts with graphic textures were observed. Grain size in the sandstones range from coarse pebble sand to fine sand or silt. Grains are usually subangular to subrounded and poorly to moderately well sorted. Three types of sandstones are recognized:

1. pebbly sandstones and lag gravels
2. thick-bedded sandstones
3. sandstones associated with mudstones

1. Pebbly sandstones form the thickest (0.5 to 2.0 m) beds. They are distinguished from conglomeratic sandstones and thick-bedded sandstones by the presence of >20 percent pebble-sized framework constituents. Rare cobbles are also present. Pebbles are restricted to the basal third of the beds and the upper portion consists of a granule to medium-grained sandstone. Pebbly sandstones are usually located at the base of channel scours associated with lag gravels. Commonly they contain well-developed basal scours. Lag gravels do not form discrete beds but form lag deposits at the base of pebbly sandstone beds in channel scours. Clasts within the lag gravels range from pebbles to boulders and usually comprise 15 to 50 percent of the rock.The most common clasts are 50 to 100 percent graphitic mudstone similar to adjoining muds, 0 to 50 percent vein quartz, 0 to 25 percent laminated chert, 0 to 20 percent trondjhemite, 0 to 15 percent quartzite, and 0 to 5 percent felsic volcanic clasts.

2. Thick-bedded sandstones range from 0.2 to 1.5 m in thickness. They are interbedded with sandstone-mudstone couplets or with pebbly sandstones. Basal scours, loading and flame structures are common in these sandstones and most of the primary structures observed occurred in these rocks.

3. Sandstone-mudstone couplets form beds <0.15 m thick, interbedded with graphitic or brown sericitic mudstone of similar thickness. These are analogous to the turbidites of Walker (1984). Bedding contacts are planar with little or no scouring. Grading and other primary structures are scarce. Sand grains may be as coarse as granule sand with occasional pebbles, but in average are a medium sand size.

Grading in the pebbly and thick-bedded sandstones is well developed and bedding planes are quite distinct in contrast to the massive amalgamated sandstones of the proximal association. Bed thickness shows a positive correlation with proximity to channel scours. Beds are laterally discontinuous (Figure 4.4), usually the result of truncation by the numerous channel scours present throughout the sequence. On islands #2 and #3, channelized beds form about 80 percent of the sedimentary sequence. Channel scour morphology alters progressively from north to south. On island #2, channel scours are laterally extensive, commonly >15 m wide. These channels truncate stratigraphy and may cut down through several metres of stratigraphy . In contrast, on islands #3 and #4, channel scours are smaller, usually only 5 to 10 m wide, and scour less deeply (*see* Figure 4.3). Within channels, sedimentary rocks commonly exhibit a fining and a thinning upward from a basal lag gravel and pebbly sandstone beds to centimetre-scale couplets of sandstone and black mudstone.

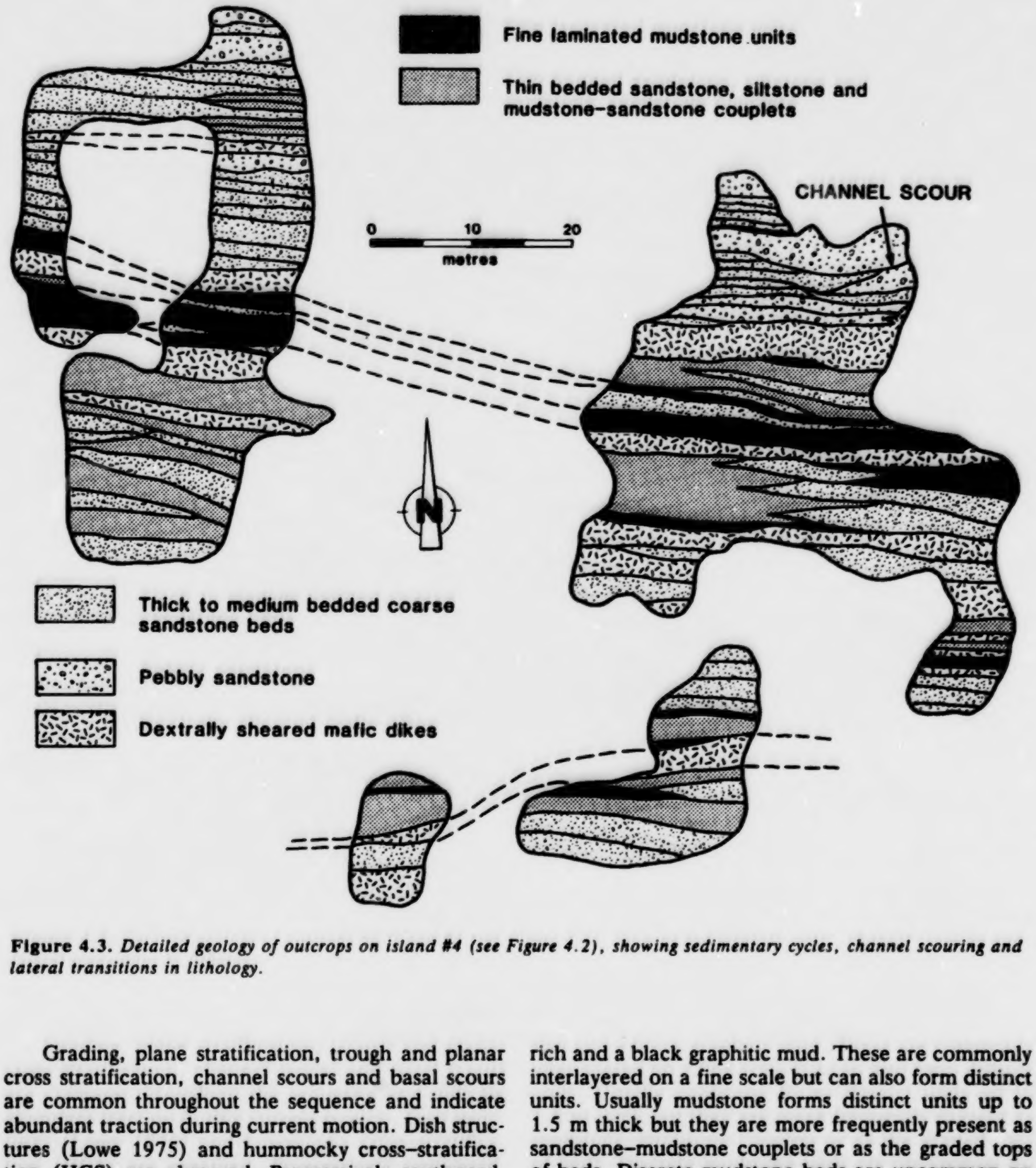
Fine laminated mudstone units
Thin bedded sandstone, siltstone and mudstone–sandstone couplets
CHANNEL SCOUR
0
10
20
metres
N
Thick to medium bedded coarse sandstone beds
Pebbly sandstone
Dextrally sheared mafic dikes

Figure 4.3. *Detailed geology of outcrops on island #4 (see Figure 4.2), showing sedimentary cycles, channel scouring and lateral transitions in lithology.*

Grading, plane stratification, trough and planar cross stratification, channel scours and basal scours are common throughout the sequence and indicate abundant traction during current motion. Dish structures (Lowe 1975) and hummocky cross–stratification (HCS) are observed. Progressively southward, HCS occurrences exhibit a decrease in amplitude, wavelength, angle of dip of hummock foresets, degree of basal scouring, and average grain size of the sand. Corresponding to this, an increase in the amount of mud and silt associated with the HCS, and in the relative lateral continuity of the beds is also observed. These changes reflect a progressive proximal to distal transition (Brenchley *et al.* 1986).

Mudstones are also prominent in the medial setting. Two types were recognized: a brown sericite–rich and a black graphitic mud. These are commonly interlayered on a fine scale but can also form distinct units. Usually mudstone forms distinct units up to 1.5 m thick but they are more frequently present as sandstone–mudstone couplets or as the graded tops of beds. Discrete mudstone beds are uncommon on island #2 but are present on island #3 and southward.

DISTAL ASSOCIATION

The precise boundary between the medial and distal associations is arbitrary, and based on the appearance of a 1:1 sand to mud ratio. The distal association is present from island #4 southward to island #7. On island #4, rocks of the medial association grade downward into distal association sedimentary

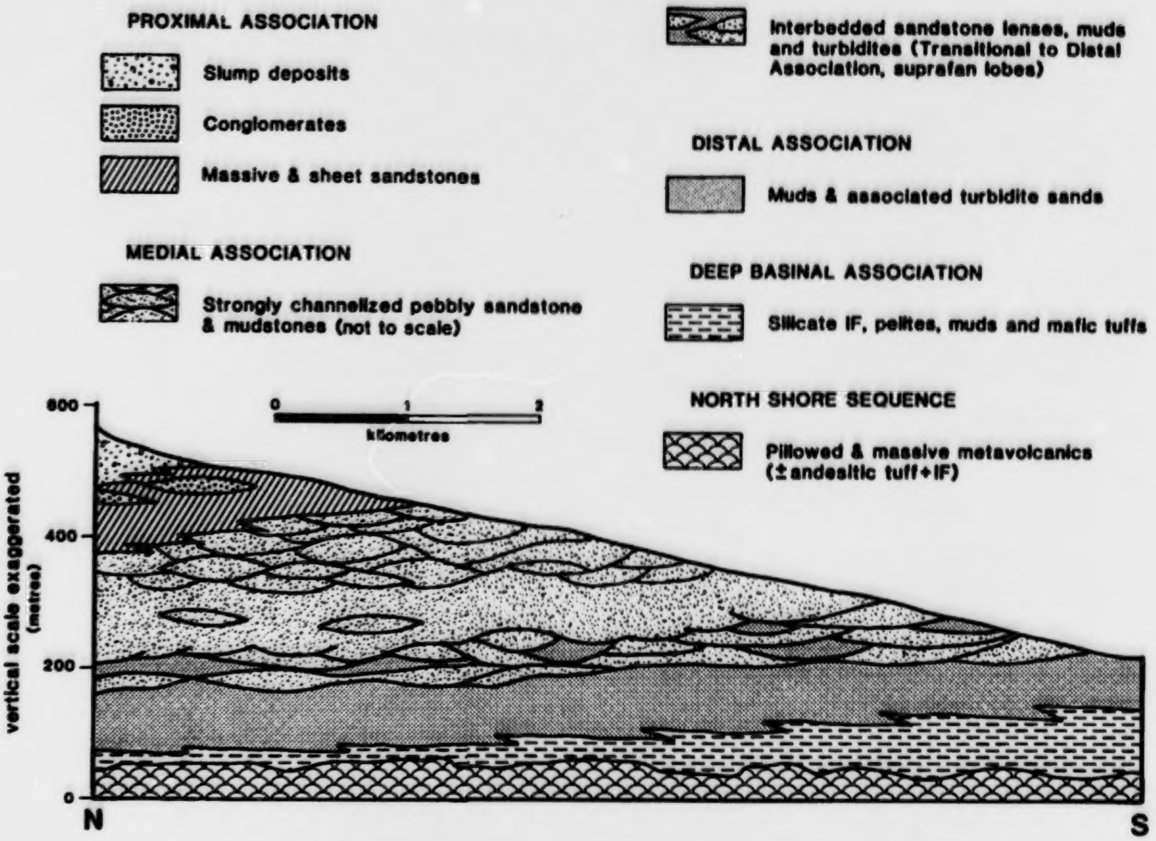
PROXIMAL ASSOCIATION
Slump deposits
Conglomerates
Massive & sheet sandstones
MEDIAL ASSOCIATION
Strongly channelized pebbly sandstone & mudstones (not to scale)
Interbedded sandstone lenses, muds and turbidites (Transitional to Distal Association, suprafan lobes)
DISTAL ASSOCIATION
Muds & associated turbidite sands
DEEP BASINAL ASSOCIATION
Silicate IF, pelites, muds and mafic tuffs
NORTH SHORE SEQUENCE
Pillowed & massive metavolcanics (± andesitic tuff+IF)
0
1
2
kilometres
600
400
200
0
vertical scale exaggerated (metres)
N
S

Figure 4.4. *Schematic cross-section of Keewaywin Sequence, showing proximal to distal transition within 500 m vertically and 5000 to 8000 m laterally, suggesting a moderate size fan (Walker 1984). IF=Iron Formation.*

rocks. On the south shore of the east mainland, rocks of the medial association grade laterally into the distal association.

Lithologies and primary structures in the distal association are essentially identical to those in the medial association. Conglomerates are absent in the distal setting except for discontinuous concentrations of pebbles at the base of beds filling poorly developed scour channels. Pebbly sandstones are largely restricted to thick-bedded sequences. Mudstone-sandstone couplets form up to 80 percent of the sequence and form units up to 80 m thick. Synsedimentary slumps with irregular folding and detachment planes are present, especially where muds are spatially associated with sandstone lenses.

On islands #5 and #7, vertical and lateral sections reveal a coarsening upward trend from west to east, and south to north in the distal association. The transition from distal to basinal setting is arbitrarily marked by the first appearance of non-pelagic terrigenous clastic detritus forming thin siltstone and less common sandstone lenses. Over the next 80 m upward, these sandstone layers become increasingly prominent, from <1 percent to 10 to 15 percent. A corresponding decrease in the proportion of chemical sediment to about 10 percent is observed. In the lower part of the first 80 m of section, the non-pelagic terrigenous units form lenses of thin-bedded Bouma DE and BDE sequences (Bouma 1962). About 40 m up the section Bouma ABDE and then ABD cycles occur. Usually, Bouma E muds are pelitic, exhibiting a garnet-biotite assemblage. At the base of the 80 m zone, the clastic lenses are enclosed within deep basinal pelagic and chemogenic sediments. Chemical sedimentary rocks disappear entirely about 20 m up section and the bulk of the sedimentary rocks enclosing the sandstone lenses is pelagic mud of the lower fan. About 60 m up the 80 m section, the sandstone units begin to coalesce and form relatively continuous sheet-like units interlayered with thick units of laminated mudstones and siltstones. The first channel scours are found here as well as the first occurrence of planar cross-bedded sands.

DEEP BASINAL ASSOCIATION

Deep basinal sediments occur on the south mainland and on the west side of islands #5 and #7 (*see* Figure 4.2). They comprise an interlayered sequence of silicate–facies iron formation, thinly laminated graphitic pelagic mudstones, garnet–biotite mudstones, diopside–rich carbonate units and granular tremolite–actinolite–rich laminae (mafic–ultramafic tuff?) or dolomitic mudstone. On the south mainland, sedimentary units of the basinal association are interlayered with massive mafic flows. On islands #5 and #7 a monotonous sequence of basinal sedimentary rocks is about 300 m thick.

STRUCTURAL GEOLOGY

The Keewaywin Sequence and adjoining North Shore volcanic rocks have been subjected to two major phases of deformation and a late shear event.

Early synsedimentary deformation is locally developed, commonly manifested as normal faulting restricted to discrete intervals of stratigraphy, but in several cases, soft sediment deformation of mudstones and iron formation has produced highly contorted folding patterns with distinct detachment planes.

Structural mapping indicates that the early interpretation of the sequence as a syncline (Thurston *et al.* 1987) is inadequate. The east and west bounding shear zones show dextral movement, but are related to separate granitoid bodies. Opposed facing directions and bedding orientations in the north part of the sequence, and adjoining North Shore Sequence volcanic rocks suggest the presence of an early northwest–trending, southeast–plunging syncline with a minor anticline and syncline developed on the east limb (*see* Figure 4.2). The west limb of the syncline extends southward to island #7 whilst the east limb trends roughly eastward. Fabric within sediments is largely controlled by proximity to the shear zones. On the east limb of the syncline, foliation is roughly parallel to bedding. On the west limb, foliation is parallel to S–fabric within the west shear zone and the contact strain aureole of the Niska Pluton. Lineations plunge steeply 60° to 70° south to southeast with local reversals adjacent to late shear zones.

The early folding has been modified by shearing and associated buckle folding along east–west–trending shear zones. This late shearing does not affect rocks north of island #4 however. Axial planar shear has also resulted in local rotation of large segments of stratigraphy. Warping of bed plane orientation from islands #5 to #7 (*see* Figure 4.2) suggest that megascopic structures adjacent to shear zones exhibit similar deformation patterns.

On islands #2 to #4, bedding rotates systematically from north–south to east–west by incremental changes in strike across intermediate dikes. These dikes trend parallel to right–lateral fault planes on island #4 and are intensely sheared while the host rock is essentially undeformed. Two S–fabrics are seen within these dikes. The first strikes roughly parallel to the dike walls, and the second strikes parallel to regional S–fabric in the adjoining sediments. The faults and dikes cut across stratigraphy and have acted as the locus for dextral shear. Abrupt changes in lithology across these dikes indicate that significant movement has occurred along them. This consistent dextral movement has juxtaposed upper stratigraphy with units of the lower stratigraphy.

Late northwest– to northeast–trending sinistral shears have caused further disruption of stratigraphy with up to 650 m of lateral offset (*see* Figure 4.2, island #8).

CONCLUSIONS

Supracrustal rocks of the Eastern Sandy Lake area represent progressive development and filling of an Archean basin. The abundant listric normal faults and sheared dikes within the Keewaywin and North Shore Sequences suggest extensional tectonics within a fault–bounded trough or on a continental margin.

The basin was floored by mafic and ultramafic volcanic rocks and associated chemogenic sediments of the North Shore Sequence. This interpretation is supported by:

1. Uniformly southeast structural facing directions in the North Shore and Keewaywin Sequences. Both sequences are folded around the north–trending syncline at the east end of Harper Bay. In this area, no shear zone separates the two units and a continuous stratigraphy is present.
2. Lithologies and the stratigraphic sequence in the North Shore Sequence and the basal volcanic unit of the Keewaywin Sequence are essentially identical. Pillowed mafic flows of the North Shore Sequence give way upward to massive flows and tuffs capped by iron formation. In the volcanic rocks of the Keewaywin Sequence, stratigraphy is identical except that the upper chemical sediments are in turn overlain by clastic sediments.

Pillowed flows, lack of abundant pyroclastic rocks and abundant intercalated pelitic sediments and iron formation throughout the North Shore Sequence suggests a calm, submarine setting. The felsic ignimbritic caldera fill on the west end of the North Shore Sequence shows evidence of partial subaerial deposition (Thurston *et al.* 1987). This suggests that at least in the west, subsidence did not match deposition. In the study area, mafic volcanic rocks floored the basin into which the Keewaywin sedimentary rocks were transported. However, the lack of volcanic rock in the terrigenous sediment suggest a hiatus in volcanism. A later magmatic event is suggested by the dikes. Lack of extrusive equivalents of the dikes prevents any further inferences.

Following volcanism a period of quiescence allowed formation of a thick sequence of pelagic and chemogenic sediments of the deep basinal association. This was terminated by progradation of a storm wave–modified fan–delta complex from the margin of the basin. The Keewaywin sedimentary sequence exhibits most features of the classic fan–delta model of Walker (1984). Based on sections across islands #7, #4 and #2, the proximal to distal transition appears to have occurred within 500 m vertically and about 5000 to 8000 m laterally. This suggests a moderate sized fan shown schematically in Figure 4.4.

Proximal association rocks on island #1 contain abundant conglomerates and slumps, and lack significant siltstone and mudstone in keeping with a classic fan delta facies model (Walker 1984). Pebbly and massive sandstone units on islands #1 and #2, and strong channelization of medial sediments on island #2 are consistent with a proximal to upper mid–fan setting. The north to south transition from sand to mud–dominated and channelized to unchannelized sedimentation is also characteristic of a typical fan–delta model where distally, flows become decreasingly channelized and development of meandering and switching suprafan lobes is more prevalent. Distal wedges of coarse clastic sediment are deposited at the edge of suprafan lobes as they prograde into the deep basin.

The presence of very mature sheet sands associated with the proximal environment on island #1 is not characteristic of a submarine fan however. The plane–laminated and medium–bedded sheet sands are more analogous to foreshore sediments in a beach or barrier setting (Reinson 1984) or nonchannelized sheet flow sandstones. Proximal association rocks on the east mainland are also not characteristic of an upper fan setting. Rounded, well–bedded, poorly stratified conglomerates and supermature, possibly cross–bedded quartzarenites are indicative of sedimentary rocks in a proximal braid plain fluvial environment (Rust and Koster 1984; Ojakangas 1985). A similar environment is postulated for Archean quartzite in the North Caribou Lake Greenstone Belt (deKemp 1987). The bimodal textures of the associated sublitharenites indicates a dual source for framework grains. One source involves significant reworking and one requires rapid deposition. Further evidence of a shallow subaqueous fan setting is suggested by the hummocky cross–stratification across the fan from the proximal to lower medial settings. Hummocky cross–stratification represents single event suspension deposits and probably reflects storm wave modification of material carried downslope as density flows (Walker 1984; Duke 1985; Swift *et al.* 1986). This suggests that the mid to upper portions of the fan–delta were shallow enough to be affected by storm events. Estimates of depth of modern storm wave base range from 2 m (Eyles and Clark 1986) to >100 m (Vincent 1986). It is speculated that the upper fan was located within the shoreface or very shallow marine environment such that a rapid alluvial to fan delta transition occurred. This seems typical of many Archean sedimentary sequences (Ojakangas 1985).

Sedimentary rocks in the lower part of the fan are less mature than the upper fan and lithic detritus is prevalent. This suggests lithic grains were transported rapidly downslope before reworking. The presence of mature, quartz–rich sediments poses a problem however. Two possible methods are proposed for concentrating such volumes of quartz. The first calls for rapid erosion of a poorly consolidated volcanic edifice with winnowing of vitric fragments and concentration of phenocrysts (Ayres 1983). The second calls for extensive single or multicycle reworking of sediment in a shelf environment to remove fines and concentrate quartz (e.g. deKemp 1987). The duality of the sediment in the case of the Keewaywin Sequence may suggest both models are relevant. The maturity of the fluvial sediments and presence of well–rounded vein quartz, chert and granitoid clasts and grains throughout the rock suggest protracted transport. The angular quartz and felsic volcanic clasts were probably derived from felsic volcanic complexes.

Such a model is compatible with that proposed by Wood and Thurston (in preparation) and Thurston and Chivers (in press) for development of the about 3.0 to 2.9 Ga platform sequences on an early sialic basement.

IMPLICATIONS FOR EXPLORATION

Archean platform sediments are similar in general type of sedimentology to sediments forming major repositories for gold and uranium such as the Witwatersrand and the Huronian. It will only be through an understanding of the sedimentology and the variation in sedimentologic environment that we can arrive at any firm assessment of the mineral potential of these sequences. The mineral deposit potential hangs directly upon parameters such as the degree of reworking and the character of the source rocks, as well as any potential alteration after deposition. These aspects await further laboratory study.

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5. Project Number 88–10. A Geological Re–evaluation of Northwestern Greenstone Belts

A.L. Cortis[1], G.M. Stott[2], I.A. Osmani[2], B. Atkinson[3], and P.C. Thurston[2]

[1]Graduate Student, University of Manitoba, Winnipeg, Manitoba.

[2]Geologist, Precambrian Geology Section, Ontario Geological Survey, Toronto.

[3]Resident Geologist, Mines and Minerals Division, Ministry of Northern Development and Mines, Red Lake.

INTRODUCTION

Revision of the Geological Map of Ontario under the Geology of Ontario program has included a reconnaissance investigation of a number of poorly known areas. Several greenstone belts in northwestern Ontario were examined in the 1987 field season (Thurston *et al.* 1987) in the Wabigoon Diapiric Axis and the Sachigo Subprovince. This examination showed that all major greenstone belts in these areas contained a new lithostratigraphic association; namely, the platform sequence, which consists of quartzarenites, iron formation, and komatiite in ascending stratigraphic order. These sequences are important in a stratigraphic and a tectonic sense. They differ in paleoenvironment from mafic to felsic cyclical volcanism as they represent continuous shallow–water deposition. Platform sequences, based on the few dated examples (Corfu and Wood 1986; deKemp 1987; Davis and Jackson 1988) are >2.85 Ga and may approach 3 Ga. Therefore they are older than most examples of mafic to felsic cyclical volcanics. The age relationship makes platform sequences the oldest greenstones in the Superior Province. They provide, in their quartz–rich character and granitoid provenance of the sediments, evidence of the widespread occurrence of granitoid units early in Superior Province history. The provenance and stable setting suggest the presence of orogenic events at about 2.8 and 3.0 Ga (Thurston and Chivers, in press).

In the light of the distribution of the platform sequences in every major greenstone belt of the Sachigo Subprovince and the Wabigoon Diapiric Axis, follow–up work in 1988 was directed to the reconnaissance of belts not examined within these areas in 1987. Localities examined are shown on Figure 5.1.

Within the Sachigo Subprovince only the western end of the Ponask–Sachigo Greenstone Belt was examined in 1987. Therefore, the eastern end of the belt on Sachigo Lake was examined this year. While the Horseshoe Lake Greenstone Belt was mapped (Jensen 1987), no recent information was available on the Windigo Greenstone Belt. In the God's Lake domain, i.e. the northern part of the Sachigo Subprovince, only the Stull Lake Volcanic Belt was examined to verify the lack of platform sequences last year. Therefore, brief visits were made to Ellard Lake, Swan Lake, and the Nemeigusabins Lake arm of the Big Trout Lake Greenstone Belt (*see* Figure 5.1). As platform sequences occur throughout Sachigo Subprovince the character of greenstone

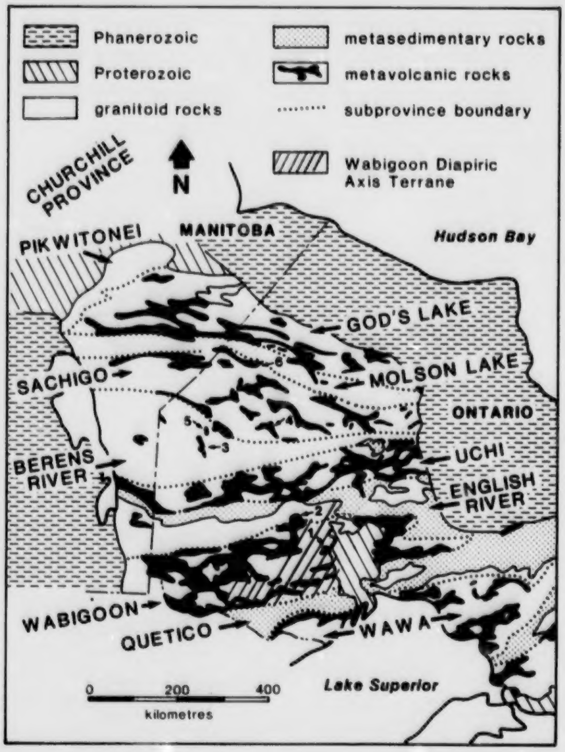

Figure 5.1. *Location Map showing the western part of the Superior Province. Subprovince and domain boundaries are shown by dotted lines. Note the revisions to the extent of the Sachigo Subprovince. Greenstone belts examined for platform sequences or mentioned in the text are numbered: 1) Obonga Greenstone Belt, 2) Savant Lake Greenstone Belt, 3) McInnes Lake Greenstone Belt, 4) Windigo Greenstone Belt, 5) Hornby Lake Greenstone Belt, 6) Ponask–Sachigo Greenstone belt.*

remnants in the Berens Subprovince is of importance. Therefore visits were made to the McInnes Lake belt and the Hornby Lake belt. Within the Wabigoon Diapiric Axis, last year's mapping disclosed shallow-water sequences in most greenstone belts. However, the Obonga Greenstone Belt was not examined because the abundant felsic metavolcanics at the western end of the belt (Thurston 1967) suggested that platform sequences would not be present. However, further analysis suggested the sequence along the southern margin of the belt was relatively poor in felsic metavolcanics and contained sediments relatively low in the stratigraphy. Therefore this sequence was examined this season.

Results of this project are to be incorporated directly into the 1:1 000 000 Geological Map of Ontario. Therefore, descriptions within this summary are of sufficient detail to encourage exploration and serve as a record of major findings until publication of the Geology of Ontario volume. The data will also be used in the planning of further mapping projects in this area.

OBONGA LAKE GREENSTONE BELT

INTRODUCTION

The Obonga Lake Greenstone Belt, located 30 miles southwest of the town of Armstrong, is traceable continuously from the Kashishibog River in the west to Obonga Lake in the east where it is covered by Keweenawan igneous intrusive sheets (Figure 5.2).

Mapping in the area followed basic field mapping carried out by Thurston (1967) and concentrated on delineating and interpreting the nature of the southern granite–greenstone contact in the area between Muller Lake and Lake "Z2" in the west, and between Silk Lake and Goosander Creek in the east (Figure 5.2). Access to this area is by means of float-equipped aircraft. Virtually the whole belt is covered by an extensive seven-year old burn which, while resulting in excellent outcrop exposure, makes movement extremely difficult.

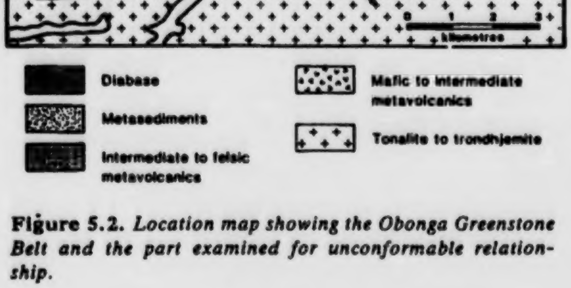

Figure 5.2. *Location map showing the Obonga Greenstone Belt and the part examined for unconformable relationship.*

Based on observations made during this study, the granite–greenstone contact can be divided into two portions separated by a large, late diabase stock. These zones comprise the following:

1. from Badour Lake west to the western end of Muller Lake
2. the area east of Badour Lake to south of Silk Lake

1.BADOUR LAKE AND WESTWARD

In this area, the granite–greenstone contact trends approximately eastward and is sharp and planar. All lithologies exhibit strong dextral shearing with a steeply (70° to 80°) northwest-plunging lineation. This intense fabric is developed pervasively throughout the supracrustals, but gradually diminishes in intensity in the granitoids over a 4 to 5 km range south from the granite–greenstone contact.

At the contact, fine- to medium-grained, massive to gneissic and schistose mafic metavolcanics are found adjacent to a tonalite to trondhjemite gneiss. In places, the gneiss is granodioritic as a result of pervasive potassic metasomatic alteration along fractures and veins resulting in *in situ* growth of potassic feldspar megacrysts. This potassic alteration also decreases in intensity southward in conjunction with the decrease in the degree of shear. The supracrustals are usually too schistose for retention of primary fabric, but in one outcrop north of Badour Lake, strongly stretched pillowed mafic metavolcanic rocks were observed in contact with sheared felsic pyroclastic rocks. All mafic volcanic rocks are plagioclase-phyric. The size and proportion of plagioclase phenocrysts varies from flow to flow. Phenocrysts can form from 1 to 40 percent of the rock and range from 5 to 30 mm in size. This variation is useful for delineating flow boundaries, even in areas where deformation is quite intense. The supracrustal rocks are also intruded by numerous mafic dikes with highly variable orientation. Some dikes closely follow flow boundaries or lithological contacts and are commonly virtually indistinguishable from some coarser-grained mafic flows. Other dikes cut across flows at high angles. All dikes are plagioclase-phyric and are essentially identical to the mafic extrusives in which they are hosted. Due to the intense deformation, no facing directions were distinguishable in the supracrustals across the map area.

On the northern shore of Badour Lake at the eastern margin of the area, the granite–greenstone contact is not simply planar. Intrusive, foliated trondhjemite dikes cut the adjacent mafic metavolcanic rocks and, in places, thin granitoid dikelets are so common as to produce a network of intrusive material hosting angular blocks of mafic metavolcanics. Also of note is a complex interleaving of granitoid and mafic rock at the creek at the northern edge of Badour Lake. In places tongues and dikes of trondhjemite cut the mafic metavolcanics, but, in other outcrops, dikes, or very large laterally continuous inclusions of mafic metavolcanics, are found within the granitoids. Late, undeformed, very fine grained pink felsite dikes cut all units. This zone possibly represents a continuation of the eastern granite–greenstone contact area described below.

2.BADOUR LAKE AND EASTWARD

The granite–greenstone contact in this area is complex and confusing given the limited outcrop, but appears to comprise a deformed granitoid regolith or altered unconformity overlain by mafic metavolcanic rocks and intruded by later granitoid dikes (Figure 5.3).

At the western end of the area (*see* Figure 3, locality 1), the granite–greenstone contact is sharp and planar. Both the mafic metavolcanics and the trondhjemite are highly schistose with a moderately northwest–plunging (48° to 60°) lineation. Supracrustal rocks consist of schistose, fine–grained, amphibolite gneiss. Gneissic banding on a millimetre to centimetre scale is defined by plagioclase segregations. Larger plagioclase phenocrysts up to 2 cm in diameter are randomly dispersed throughout the gneiss. Small pods and lenses of epidote–quartz–plagioclase are also randomly interspersed. In some places about 10 percent of the volume of the rock is taken up by numerous fabric–parallel quartz veins and lenses. Trondhjemite dikes up to 2 m wide cut this gneiss. These dikes have planar boundaries and contain no apparent assimilation of mafic material. They consist of a medium–grained, homogeneous, and equigranular quartz–plagioclase–biotite assemblage. Plagioclase crystals are relatively unaltered and only exhibit minor alteration. The dikes cut the supracrustals with about a 10° discordance. A subtle difference in preservation of plagioclase is noted between the dikes in the mafic metavolcanics and the granitoid to the south of the contact. The main granitoid body is coarse– to medium–grained, homogeneous and equigranular, but contains highly saussuritized feldspars, in contrast to the unaltered plagioclase of the dikes. None of these dikes were seen intruding the body to the south, however. This makes the discrimination of the dikes and the main body of the granitoid as separate phases difficult.

About 150 m farther east, the contact is marked by a long (100 m) scarp (*see* Figure 5.3, locality 2). Numerous mafic dikes, sills, and stocks cut the granitoids at angles to the contact which range from 0° to 90°. These bodies are mineralogically and tex-

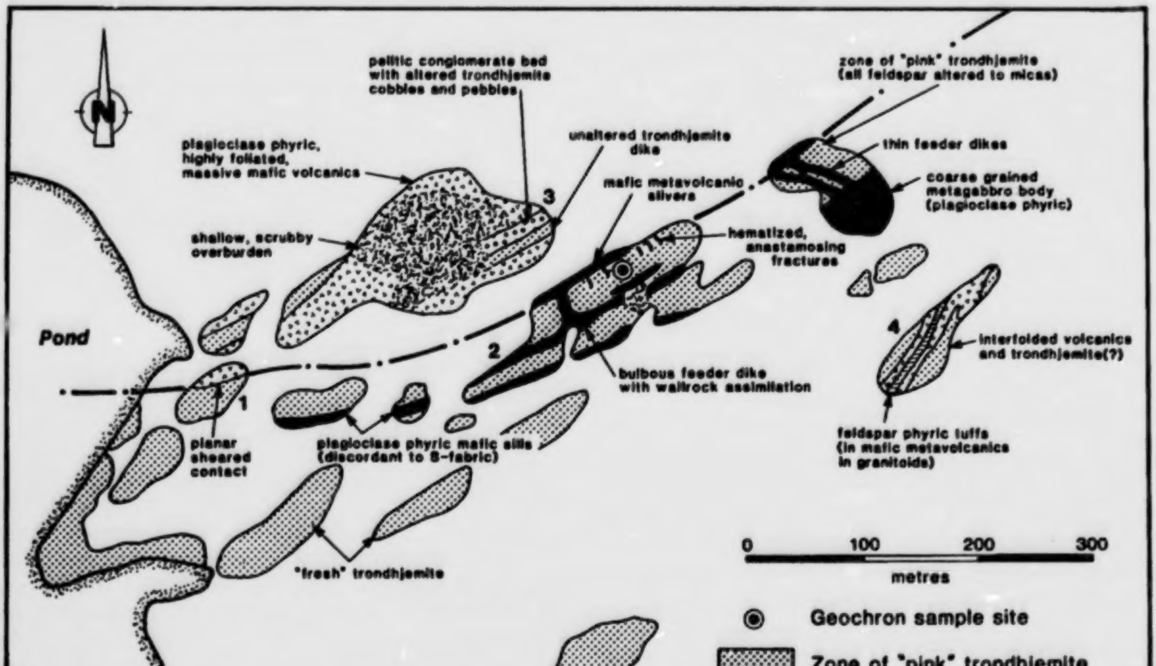
N
pelitic conglomerate bed with altered trondhjemite cobbles and pebbles
zone of "pink" trondhjemite (all feldspar altered to micas)
plagioclase phyric, highly foliated, massive mafic volcanics
unaltered trondhjemite dike
thin feeder dikes
mafic metavolcanic slivers
coarse grained metagabbro body (plagioclase phyric)
shallow, scrubby overburden
hematized, anastamosing fractures
3
Pond
2
4
interfolded volcanics and trondhjemite(?)
bulbous feeder dike with wallrock assimilation
1
planar sheared contact
plagioclase phyric mafic sills (discordant to S-fabric)
feldspar phyric tuffs (in mafic metavolcanics in granitoids)
"fresh" trondhjemite
0
100
200
300
metres
Geochron sample site
Zone of "pink" trondhjemite

Figure 5.3. *Detailed map of the southern part of the Obonga Greenstone Belt. The volcanic–granitoid contact is shown as the heavy dot–dash line. Mafic sills in the trondhjemite are shown in solid black. The area underlain by metavolcanics is shown in the "v" pattern; the trondhjemite in dots. The area of the unconformity is at locality 2.*

turally identical to mafic volcanic rocks along the length of the granite–greenstone contact, but are clearly intrusive into the granitoid. The width of individual bodies is highly variable given the irregular nature of the contacts. The larger, contact–parallel bodies (sills) are up to 5 m wide and laterally continuous for about 150 m. A large ovoid body of metagabbro about 20 by 30 m was seen on one outcrop within the trondhjemite. Although it is coarser grained than the dikes, sills, and flows, it is mineralogically identical and also contains phenocrysts of plagioclase similar to those in the other mafic bodies. This metagabbro is inferred to represent the lateral continuation of one of the sills. In contrast, dikes (i.e. contact–discordant bodies) range from 0.05 to 0.5 m thick and are only continuous for 5 to 15 m. In two areas (*see* Figure 5.2) dikes with irregular, bulbous contacts were observed leading from the sills and the metagabbro into the overlying mafic metavolcanics. Where these feeder dikes pass beyond the upper contact of the granitoid and into the supracrustals, they exhibit a fountaining effect with a lateral spreading of the dike material into flows. Similar fountaining of dikes into flows are seen in recent basalts of the Snake River Plain, Idaho (Greeley *et al.* 1977).

Some of the dikes and sills appear to be zoned, with an outer quartz–rich margin contaminated by stoping and melting assimilation of the trondhjemite wall rock, and an inner, uncontaminated zone lacking inclusions of granitoid or any modal quartz. Inclusions of trondhjemite in the outer zones of these dikes are up to 1 to 3 m in diameter and often exhibit diffuse boundaries with the mafic material.

The trondhjemite cut by these dikes is highly saussuritized with nearly complete conversion of feldspars to mica. The top 5 to 10 m of the body near the contact is pink hued, with the intensity of the hue increasing toward the contact. A similar pigmentation of the trondhjemite is also noted adjacent to a large sill and feeder dike system and extends about 2 to 3 m into the wall rock (*see* Figure 5.3, locality 2). This colour is apparently caused by the presence of finely disseminated hematite within the rock. Within this "pink" trondhjemite zone the original coarse– to medium–grained equigranular texture is totally lost. Instead, the rock assumes an inequigranular form, with very fine–grained mica and coarser, unaltered quartz aggregates. Within this oxidized zone are numerous anastomosing fractures oriented essentially normal to the contact. These are the loci of especially intense hematite oxidation, with haloes commonly extending up to 20 to 30 cm into the surrounding rock. In several localities, these fractures were seen to enclose large (0.1 to 1.0 m) angular blocks of pink trondhjemite. Where closely spaced, this fracture system forms a network, imparting a rubbly appearance to the rock.

Immediately above the contact, mafic metavolcanic rocks are very fine grained to hornblende porphyroblastic but ubiquitously plagioclase phyric. They appear identical to the mafic metavolcanics seen in the western area, and to the dikes and sills in the adjacent trondhjemite. Where recognizable, mafic flows are generally 1 to 2 m wide, and massive. Some <1 m thick, felsic to intermediate, fine–grained to plagioclase–phyric tuff horizons occur between some flows. A single 2 to 3 m wide sedimentary horizon was also found interbedded with the mafic flows (*see* Figure 5.3, locality 3). This unit consists of a polymictic, very fine grained, matrix–supported, pebble to cobble (and rarely boulder) conglomerate. Angular cobbles to pebbles of altered trondhjemite, similar in size, shape, and appearance to fracture–bounded blocks in the regolith, are supported by a pelitic matrix. The matrix comprises about 60 percent of the rock and consists of a fine–grained garnet–biotite assemblage. Between 10 to 15 percent of the clast population consists of rounded to angular, vein quartz and aphyric felsic volcanic pebbles and cobbles.

About 500 m farther eastward and in a small outcrop southeast of the contact, the relationship of granitoids and supracrustals is not as clear. In the small outcrop (*see* Figure 5.3, locality 4), the trondhjemite and the supracrustals appear to be interfolded. The contact here is sharply planar, lacks any type of alteration, and trends roughly normal to that of the contact to the north. The supracrustals appear to form a wedge–shaped body enclosed within sheets of trondhjemite, but lack of sufficient exposure precludes resolution of this problem. To the east, mafic rocks and trondhjemite exhibit abundant, conflicting crosscutting relationships. Mafic dikes are found crosscutting trondhjemites, and trondhjemite dikes are seen to cut mafic units. The exact locality of the contact is uncertain given the highly variable proportions and trends of the dikes of both lithologies. More detailed mapping is required to ascertain the exact nature of the contact in this zone.

CONCLUSIONS

The granite–greenstone contact to the west of Badour Lake exhibits features suggesting an intrusive relationship between the trondhjemite gneiss and the supracrustal rocks. The contact is planar, and dikes of trondhjemite are seen to intrude the supracrustals in numerous places. No evidence was found to suggest that the granitoids predate the volcanic rocks.

The contact east of Badour Lake exhibits conflicting evidence for the presence of older sialic rocks. The trondhjemite body exhibits many textural and mineralogical features similar to those in the tonalite–trondhjemite body to the west; however, the granitoid in the west is gneissic whereas that in the east is not. Furthermore, the body in the east is cut by numerous mafic dikes and sills. These clearly postdate the granitoid and exhibit the effects of contamination imparted by assimilation of the wall rock.

Several features of these dikes suggest that they are subvolcanic bodies emplaced in a pre-existing granitoid basement.

1. The textural and mineralogical similarities between the dikes and the volcanic rocks suggest that they are derived from the same magma body. This is especially indicated by the ubiquitous occurrence of large plagioclase phenocrysts in all the mafic units.
2. The fact that dikes can be traced from some sills into flows suggest that the intrusive bodies were shallow subvolcanic feeders. The fountaining textures exhibited at the interface of the dike and the flow is similar to that found in recent volcanic rocks of the Snake River Plain, Idaho (Greeley *et al.* 1977).
3. The hematitization haloes within the trondhjemite adjacent to the larger sills and feeder dikes and along the granite–greenstone contact suggest that the granitoid was subsequently modified by intrusion/extrusion of the mafic igneous rocks (i.e. older sialic rocks). The particularly intense alteration along fractures normal to the contact suggest that this is due to a mixed thermal and chemical effect imparted by movement of gasses from the subvolcanic bodies to the surface.

The presence of granitoid dikes clearly postdating the mafic volcanism conflicts with the above conclusions. The fact that these dikes appear relatively unaltered while the granitoids adjacent to the contact are highly altered suggest that these dikes may in fact be part of a later event. Lack of crosscutting relationships in the granitoids poses some problems. Similarly, the intertonguing supracrustal–granitoid relationships seen to the east and south also suggest that a simple contact is not present. Further work is required to solve these problems.

The granitoid–supracrustal boundary is not a true unconformity in that a true erosional boundary is not discernible. Alternatively, the contact is also neither a regolith nor a paleoweathering profile in that a soil horizon is not developed along the contact. However, the fact that erosional equivalents of the granitoid are found in a conglomerate within several metres of the contact suggests that in some places the granitoid was subjected to weathering. The hematitization adjacent to the contact is accompanied by an intense saussuritization of the plagioclases in the trondhjemite. The zone of saussuritization is wider than that of the hematite staining and increases in intensity toward the contact. Possibly this represents an *in situ* weathering or alteration profile imparted either by climatic effects or by volcanism. Beyond the presence of a few pillowed flows several hundred metres above the contact, it is uncertain as to what type of environment the volcanism occurred in. No evidence for a shallow-water setting is evident here; however, adjacent greenstone belts in the Wabigoon Diapiric Axis contain evidence for shallow water or subaerial volcanism and sedimentation (Thurston and Davis 1985; Thurston *et al.* 1987), and thus it is possible that a similar environment existed here.

SAVANT LAKE GREENSTONE BELT

INTRODUCTION

Mapping in the Savant Lake area followed reconnaissance work north of Kashaweogama Lake last year (Thurston *et al.* 1987) in which (>2.780 Ga) Jutten Volcanic Group rocks were found to host two chert to banded iron formation horizons and minor quartzose siltstones, but lacked any platformal association. This year, mapping focused on a thin unit of sedimentary rock contained within massive and pillowed mafic volcanic rocks of the Jutten Group north of Savant Lake (Figure 5.4) as reported by Trowell (1986). Although some unresolved structural complexity has affected these rocks, they appear to form a generally northwest-facing medial to distal fan which is the equivalent (Walker 1984) of a typical alluvial to shallow marine platform setting (Ojakangas 1985). This sedimentary unit is henceforth referred to as the Jutten sedimentary sequence.

GENERAL GEOLOGY

Although a classic platform association of quartzite–carbonate iron formation–komatiites–felsic volcanics (Wood and Thurston, in press) was not observed in its entirety, the limited exposure suggests such a sequence may be present. Mature sandstones, conglomeratic sandstones, and conglomerates intimately associated with a fuchsite–chert chemical–metasedimentary horizon and a sheared, fine–grained, possibly ultramafic unit were found in the southern portion of the Northeast Arm of Savant Lake (Figure 5.5, locality 1).

At this locality, a south–facing sequence of sheared fine–grained, and massive, mafic to ultramafic flows is overlain with some stratigraphic discontinuity by a highly deformed chemical and clastic metasedimentary unit. This unit is >15 m thick and contains millimetre– to centimetre–scale banded fuchsitic chert and white chert that is interlayered with minor, thinly to medium–bedded (5 to 20 cm), medium–grained quartzwacke to quartzarenite beds. All beds exhibit identical deformation and resultant recrystallization. These beds are in turn overlain, with some stratigraphic discontinuity, by a wedge of sediments grading upward from thickly to very thickly bedded boulder to cobble, and cobble to pebble, conglomerates. These conglomerates have a quartz matrix and are massive to graded, with some sandstone interbeds. This sequence exhibits a series of fining–upward cycles over a distance of 7 m (Figure 5.6). Commonly, these fining–upward cycles have an upper unit of fine sand,

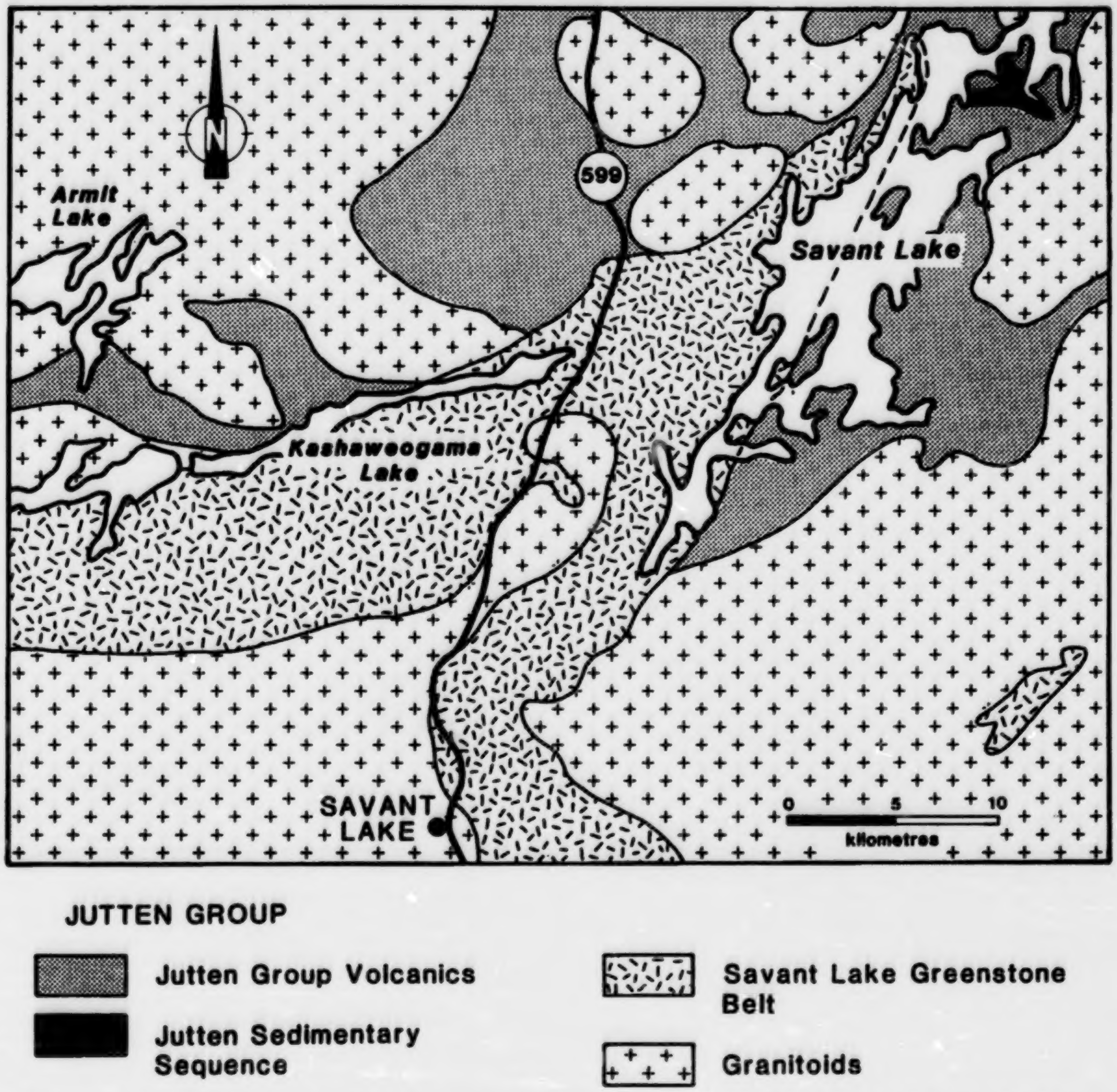
N
Armit Lake
599
Savant Lake
Kashaweogama Lake
SAVANT LAKE
0 5 10
kilometres
JUTTEN GROUP
Jutten Group Volcanics
Jutten Sedimentary Sequence
Savant Lake Greenstone Belt
Granitoids

Figure 5.4. *The Savant Lake Greenstone Belt. Geology after Trowell (1986) with the area of Jutten Group metasediments shown in solid black.*

wacke, or mudstone, indicating periodic hiatuses in sediment supply. The sequence is capped by 4 cm of chlorite– and biotite–bearing, graded, thinly– to medium–bedded wackes and rare mudstone with occasional conglomeratic beds (*see* Figure 5.5, locality 2). Several hundred metres farther south, a series of outcrops suggests intertonguing of sandstone and conglomerate with wacke–mudstone couplets which are predominant to the south and east. This may possibly reflect a medial– to distal–fan transition. The conglomerates are polymictic, containing a wide assortment of lithological clast types including ultramafic and mafic metavolcanics, vein quartz, fine– to medium–grained tonalite and trondhjemite, clastic metasediments, fuchsitic chert and a high amount of felsic to intermediate volcanic clasts, most notably aphyric grey to white rhyolite and rhyodacite clasts. Also present are rare banded iron formation and quartz–plagioclase–phyric porphyry clasts.

A notable dichotomy in clast angularity is seen across the Jutten sedimentary sequence, with fuchsitic chert and volcanic clasts being mostly angular, and the white chert, vein quartz, and granitoid clasts exhibiting a markedly high degree of rounding. This may possibly reflect a dual source for the sediment as is also indicated by cannibalization of pre–existing sedimentary units.

Midway through the sequence (*see* Figure 5.5, locality 3), a series of outcrops indicates the possible

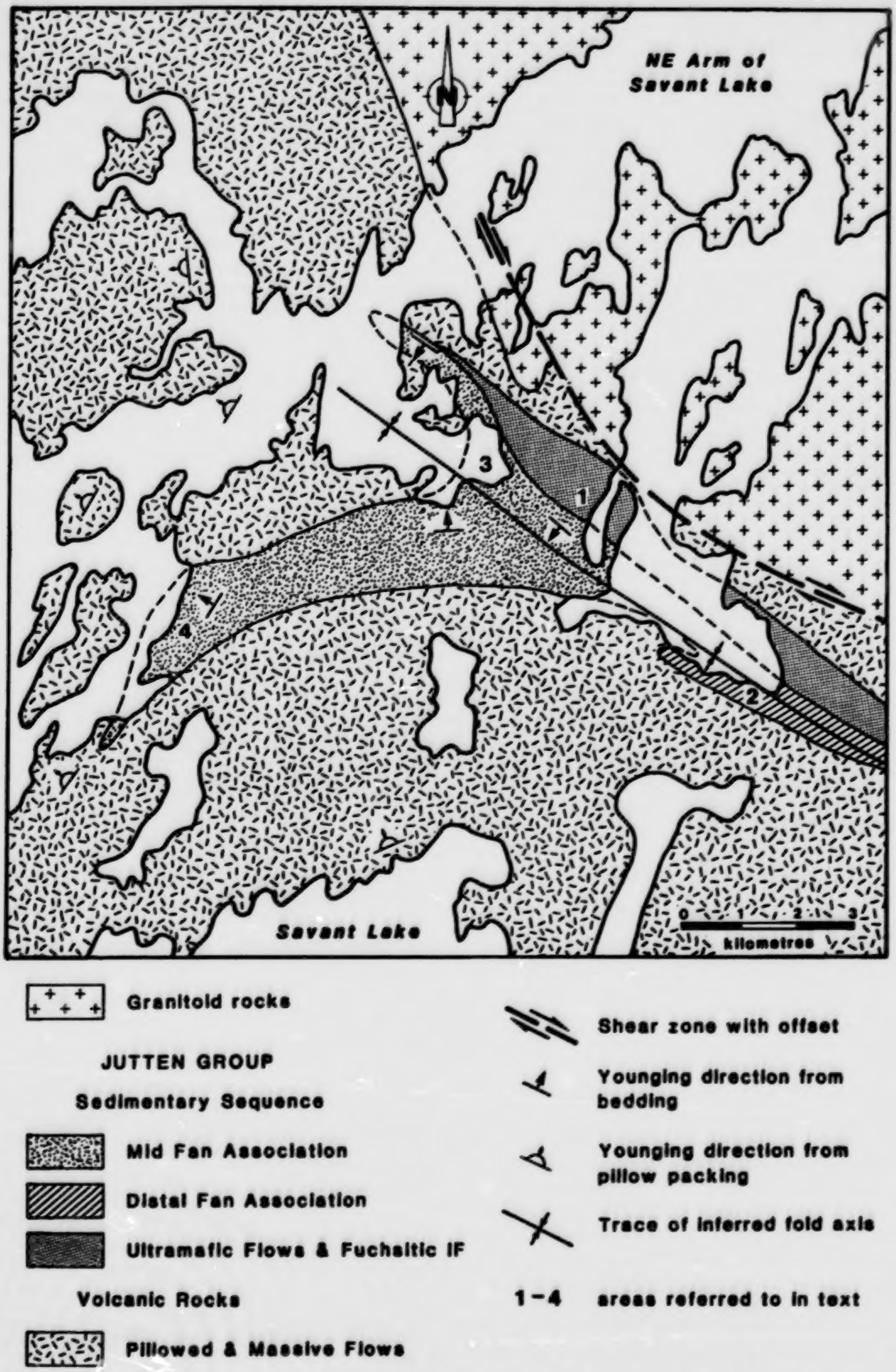
N
NE Arm of Savant Lake
Savant Lake
1
2
3
4
0 1 2 3
kilometres
Granitoid rocks
JUTTEN GROUP
Sedimentary Sequence
Mid Fan Association
Distal Fan Association
Ultramafic Flows & Fuchsitic IF
Volcanic Rocks
Pillowed & Massive Flows
Shear zone with offset
Younging direction from bedding
Younging direction from pillow packing
Trace of inferred fold axis
1 – 4 areas referred to in text

Figure 5.5. *Detailed map of the Jutten Group metasediments, in part after Trowell (1986). Most younging symbols were derived from the present mapping.*

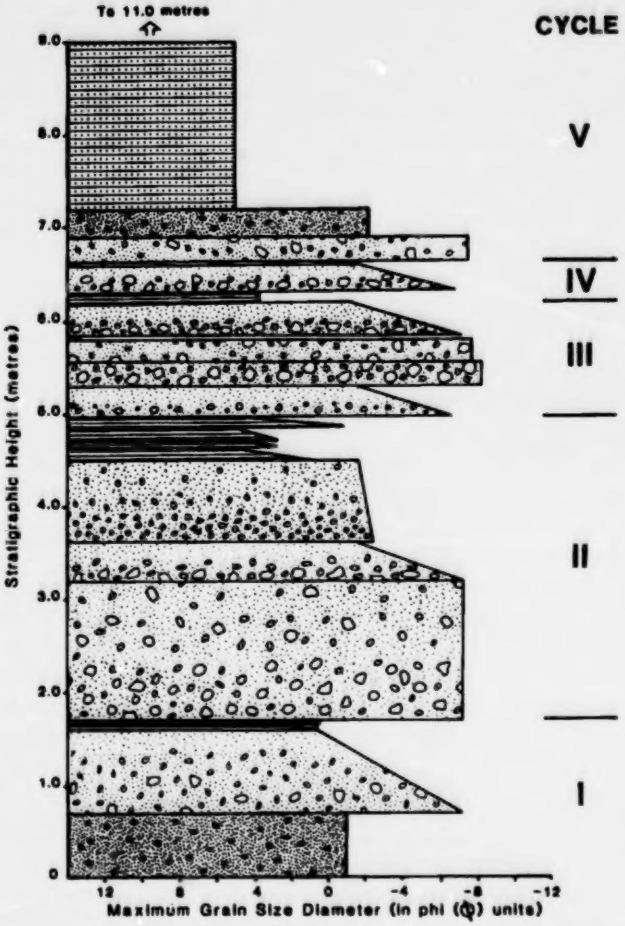
To 11.0 metres
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0
Stratigraphic Height (metres)
12
8
4
0
-4
-8
-12
Maximum Grain Size Diameter (in phi (ϕ) units)
CYCLE
V
IV
III
II
I

Figure 5.6. *Stratigraphic columns showing fining-upward cycles in the Jutten metasediments: conglomerates (coarse pattern with rounded clasts), sandstones (fine stipple with finer-grained clasts), argillites (horizontal ruling), conglomeratic wacke and fine-grained sandstone (mixed dots and horizontal ruling). The horizontal axis portrays the grain size of individual units in phi units (ϕ) with grain size increasing to the right.*

presence of a fold closure in the sediments, with different exposures separated by massive mafic volcanic rock and exhibiting opposing younging directions (although the structural facing direction appears to be generally northwestward in all cases). Here the sequence exhibits interbedding of conglomerates and sandstone with a notable lack of fines (wackes to mudstones) (Figure 5.7). The sandstones are generally coarse- to medium-grained quartzarenites and wackes, containing rounded to subangular, fairly well sorted quartz, rare plagioclase and very rare fuchsitic chert-lithic detrital grains in a muscovite and biotite matrix. Biotite and chlorite are much more prevalent in the more medial to distal setting.

On the western margin of the sedimentary unit, conglomerates and sandstones are again intimately spatially associated with volcanic rock (Figure 5.5, locality 4). The sedimentary sequence is bounded above and below by northwest-facing pillowed mafic metavolcanics, implying subaqueous deposition. The sedimentary rocks consist of interbedded sandstones, conglomeratic sandstones and conglomerates. Graded medium- to thick-bedded sandstones predominate over conglomeratic units, although conglomerates carry very large boulders, commonly interspersed with pebbles and cobbles. The sandstone beds exhibit a repetitive fining-upward sequence with coarse- to medium-grained, fairly well sorted, rounded to subangular quartzwackes to quartzarenites grading upward into fine-grained sand and silt, often with a 1 to 10 mm capping of green fuchsitic or muscovitic chert. The matrix of the coarse-grained base of these graded beds is muscovite and iron-carbonate-bearing. They weather a deep brown colour, probably due to alteration of iron-bearing heavy minerals in the matrix to iron carbonate during diagenesis (L.D. Ayres, Professor, University of Manitoba, personal communication,

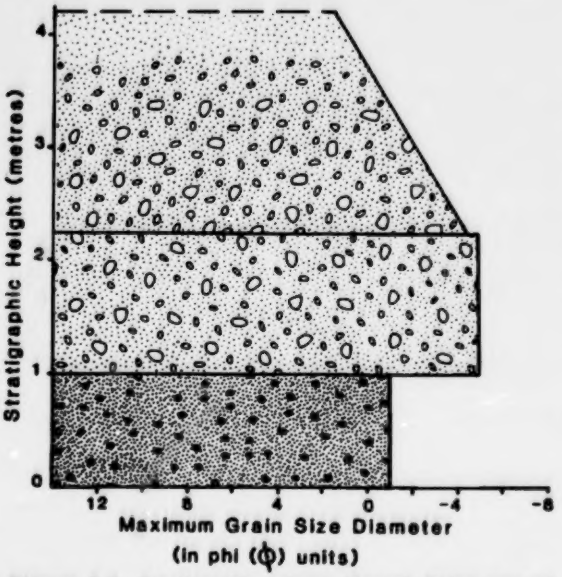

Figure 5.7. *Stratigraphic column through fining-upward conglomerates with the horizontal axis portraying average clast size in phi units (ɸ) (size increasing to the right).*

1988). A sample of these sandstones was obtained for geochronological analysis. Conglomeratic sandstones and conglomerates tend to be very thickly bedded (>1.5 m) in contrast to sandstones, but contain a matrix very similar to that of the sandstones. Very often these beds grade upward into mature, well rounded, coarse quartzarenites. A notable feature of the conglomeratic sandstones is the abundance of rounded chert pebbles and angular fuchsitic chert and yellow, sericitized, fine-grained felsic volcanic or mudstone clasts. These clasts appear to be identical to those seen in other pebbly conglomerates in the lower sequences of other platformal sequences (Thurston *et al.* 1987; deKemp 1987). A modal count of one conglomeratic bed revealed 46 percent quartzarenite matrix, 17 percent chert clasts (including fuchsitic and white chert), 13 percent mafic and intermediate volcanic clasts, 10 percent quartz phyric trondhjemite to tonalite clasts, 2 percent felsic volcanic clasts, 2 percent ultramafic clasts, 8 percent quartz and plagioclase phyric porphyry clasts, and 1 percent sericitic mudstone and vein-quartz clasts, respectively.

CONCLUSIONS

The Jutten platform sequence appears to reflect the subaqueous medial- to distal-fan equivalent of a classic platformal association and is spatially associated with pillowed and massive, mafic to ultramafic volcanic rocks and a laminated fuchsitic-chert unit. Analyses of clast populations in the conglomerate suggest a multiple-source terrace consisting of granitoid, volcanic, and sedimentary rocks subsequently reworked downslope. Although a significant proportion of the finer quartz is likely to have been supplied to the sediment from felsic volcanic rocks, the coarser fraction (>4 mm) is most likely to have been derived from the granitoid rocks present as clasts in the conglomerate. Geochronology may possibly indicate dual ages of zircon provenance. Given that the Jutten Volcanic Group is at least >2.78 Ga (Thurston and Davis 1985) it is likely that these rocks will produce a date more conformable to the classic platform sequences (2.9 to 3.0 Ga) seen elsewhere in the Superior Province. This will serve as partial confirmation of the Wabigoon Diapiric Axis as a possible old cratonic area, as suggested for the Obonga Lake Greenstone Belt (this report), and by geochronology (Thurston and Davis 1985).

McINNES LAKE GREENSTONE BELT

LOCATION AND ACCESS

The McInnes Lake area is 137 km (85 miles) north of Red Lake, Ontario, at Latitude 52°12'N and Longitude 93°45'W. Access is by float-equipped aircraft.

Excellent exposure along the entire eastern shoreline of the lake from Southeast Bay to the Northwest Arm including all of Power Bay, has been facilitated by a recent burn. In contrast, outcrops on the western shore are extensively overgrown.

PREVIOUS WORK

The area was mapped by Averill (1968) and the results incorporated into a compilation map of the Berens River block (Ayres *et al.* 1973). In 1981, 12 areas across the belt were staked by Cominco Limited. Detailed geophysical surveys were performed on some grids and five drillholes sunk in an attempt to locate base metal mineralization. More recently, in 1986, B. Atkinson, Resource Geologist at the Red Lake Resident Geologist's Office, examined several showings in the belt.

REGIONAL SETTING

The supracrustal rocks of the McInnes Lake Greenstone Belt are surrounded by older tonalite gneiss and younger granitoid plutons of the Berens River Subprovince. In contrast to the dominantly east-trending greenstone belts within the Uchi and Sachigo subprovinces, the dominant trend of the McInnes Lake belt is roughly northward. Also, in contrast to the Uchi and Sachigo subprovinces, the overall metamorphic grade of the McInnes Lake belt is much higher, ranging from upper to lower amphibolite facies.

GENERAL GEOLOGY

The McInnes Lake Greenstone Belt is a complex assemblage of metamorphosed intrusive and extrusive igneous rocks ranging from ultramafic to felsic in composition, with associated epiclastic and chemical metasedimentary units. Based on lithological assemblages, marker horizons, limited facing directions, and structural considerations, it has been possible to subdivide the supracrustal rocks into three cycles (Figure 5.8). Although approximate thicknesses of units are given, these are only apparent thicknesses. The presence of numerous shear zones within stratigraphic units and thrust faults at the margin of the belt suggests possibly that units are tectonically thickened by imbrication and repetition of stratigraphy.

Cycle I

Cycle I comprises volcanic and sedimentary rocks, and forms the dominant unit in the belt (*see* Figure 5.8). It is a simple mafic to felsic volcanic cycle with about 80 percent of the rocks comprising intermediate tuffs and tuffaceous metasediments. It is the most extensive of the three cycles and is traceable across the entire belt. It is divided into two parts, a lower mafic metavolcanic unit of limited extent, and an upper felsic to intermediate pyroclastic and epiclastic unit.

In the northern part of the belt, limited top indicators suggest a uniform east–facing direction for the cycle. In the south, top indicators are lost except for one graded unit which is west facing. The cycle is divisible into two parts; a thin basal mafic metavolcanic unit, and a laterally extensive thick upper unit dominated by dacitic tuffs.

Basal mafic metavolcanics of Cycle I are restricted to the northern part of the belt on the northwest arm of the lake. They form a southeast–striking unit, about 300 m thick. No facing directions were preserved in this unit. Due to its proximity to the granite–greenstone boundary, most exposures of the unit are usually strongly sheared and/or contain hornblende porphyroblastics such that most primary fabric is overprinted. However, in places massive flows averaging 2 m in thickness are seen. Epidote pods and lenses in some sheared outcrops may suggest that they were originally pillowed. Mafic flows persist throughout the cycle, but form less than 2 to 3 percent of the upper unit.

The upper unit of Cycle I is composed almost entirely of dacitic and andesitic tuffs and flows. Tuffs are generally fine grained and thinly bedded or gneissic. Most tuffs contain from 0 to 20 percent, 1 to 10 mm, rounded plagioclase and/or quartz phenocrysts. In the central part of the lake, the proportion of phenocrysts can reach 50 to 60 percent, forming thick–bedded crystal tuff units. Grading is not well developed in most of the tuffs, and facing directions are difficult to obtain. Coupled with this, deformation and high metamorphic grade have resulted in overprinting of most primary structures.

Pyroclastic rocks on the main body of McInnes Lake, immediately west of Power Bay (*see* Figure 5.8), are much coarser grained than the bulk of the tuffs in Cycle I. They are composed of well–bedded and normally graded tuffs, lapilli–tuffs, and tuff–breccias. Beds range from 0.3 to 2.5m thick and are laterally continuous over tens of metres. Beds contain up to 40 percent quartz and plagioclase phenocrysts ranging from 1 to 20 mm in diameter. Lithic fragments include both essential fragments and accessory fragments of mafic metavolcanic rock, range from ash to bomb sized, and exhibit well developed normal grading. Pumiceous fragments are uncommon. Where observed, they are highly stretched and are usually located at the top of beds. They consist of fine–grained quartz–feldspar aggregates 1 to 10 mm long which exhibit only slight retention of primary vesicularity.

On the northern part of the lake, west of Power Bay, Cycle I rocks are intruded by numerous east–striking mafic dikes. The dikes vary in width from 0.5 to 3 m and are restricted to an approximately 1.5 km wide zone on the western shore where they comprise up to 40 percent of the outcrops. They exhibit planar, unsheared boundaries normal to the trend of Cycle I lithologies, and intrusion seems to have been along simple dilational fractures. Both the dike rocks and the wall rocks are cut by the same deformation fabric. The dikes exhibit a fine–grained hornblende–plagioclase assemblage which appears texturally and mineralogically identical to mafic metavolcanic rocks of Cycle II.

A series of late peridotite sills are seen to intrude Cycle I rocks across the entire length of the belt (*see* Figure 5.8). These ultramafic intrusive bodies are unique to Cycle I and are generally emplaced parallel to primary layering, although some discordance up to about 15° was seen. Although the sills form a series of discrete sheets, each several hundred metres long, they appear to have been intruded roughly at the same stratigraphic level in the upper unit of Cycle I. They are variably very coarse grained to medium grained, equigranular, and homogeneous. Primary olivine–pyroxene mineralogy is pseudomorphically altered to talc, tremolite–actinolite, and serpentine. The rocks are cut by the same deformation fabric as the enclosing Cycle I rocks. Close to and along the Cycle I–Cycle II boundary, numerous gabbroic sills and small intrusive bodies are present. These are variably sheared to massive, and are coarse to medium grained. The bodies can range from small sills to large laterally continuous sheets and stocks. Some of the bodies are plagioclase phyric, and texturally and mineralogically resemble Cycle II mafic volcanic rocks.

Intimately associated with Cycle I pyroclastic rocks in the central McInnes Lake area are epiclastic sedimentary units. These comprise sandstone–mudstone couplets of probable turbiditic origin, quartzose and quartzo–feldspathic sandstones, and conglomerates.

Sandstone–mudstone couplets are found interbedded with fine–grained tuffs and conglomerates

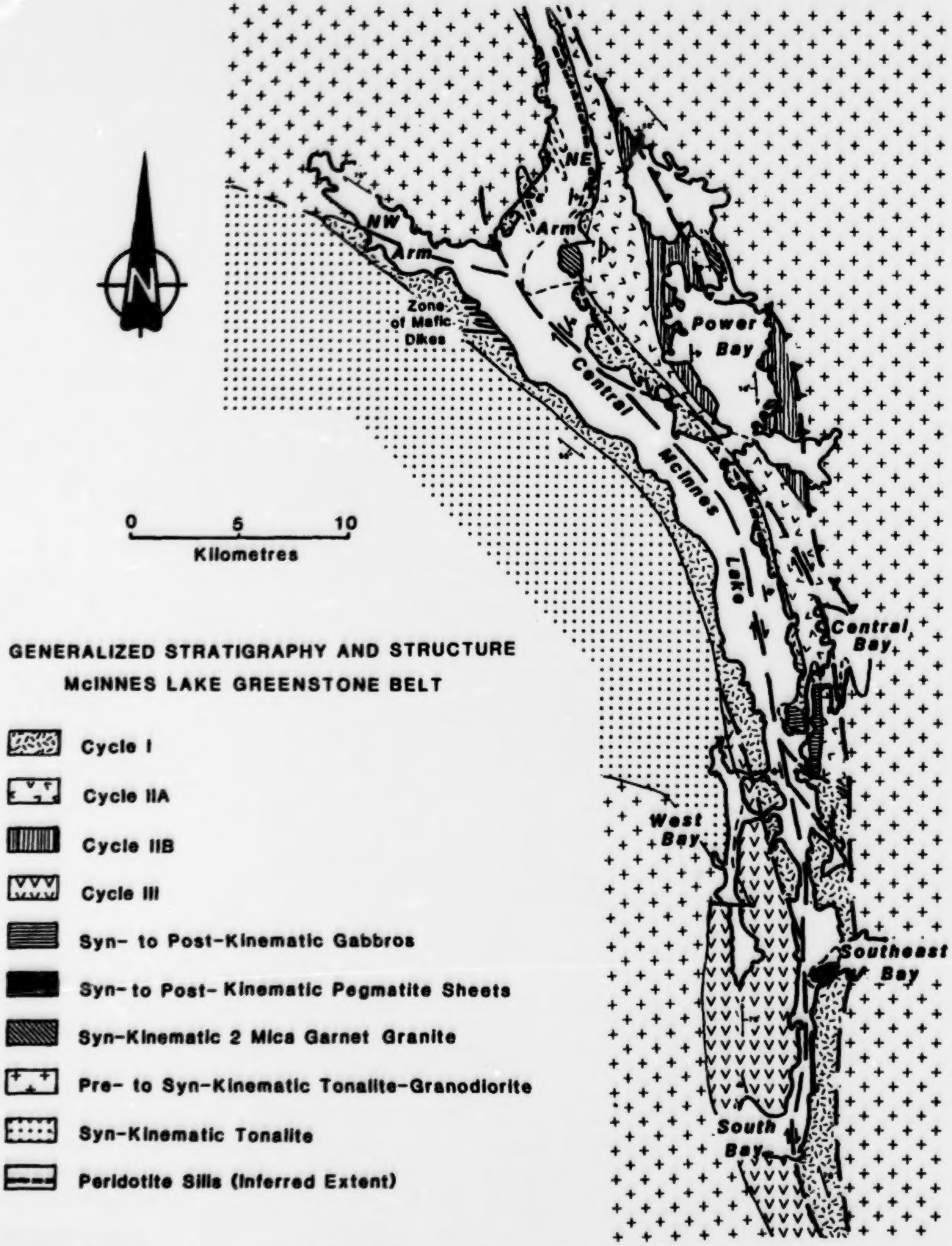
N
NE Arm
NW Arm
Zone of Mafic Dikes
Power Bay
Central McInnes Lake
Central Bay
West Bay
Southeast Bay
South Bay
0 5 10
Kilometres
GENERALIZED STRATIGRAPHY AND STRUCTURE
McINNES LAKE GREENSTONE BELT
Cycle I
Cycle IIA
Cycle IIB
Cycle III
Syn- to Post-Kinematic Gabbros
Syn- to Post- Kinematic Pegmatite Sheets
Syn-Kinematic 2 Mica Garnet Granite
Pre- to Syn-Kinematic Tonalite-Granodiorite
Syn-Kinematic Tonalite
Peridotite Sills (Inferred Extent)

Figure 5.8. *Generalized geological map of the McInnes Lake Greenstone Belt. Geology derived from the present survey with some information from Ayres et al. (1973).*

near the entrance to Power Bay and on the western shore of the lake. They consist of alternating, thinly bedded, black, cordieritic mudstones and fine-grained tuffaceous sandstone beds. Beds exhibit planar contacts with little evidence of scour. Commonly, sandstones exhibit upward grading into mudstone that is marked by a reverse grading of post-kinematic cordierite. The lithologies exhibit well developed Bouma BDE and BE sequences. No cross-laminated units were observed. Such structures are typical of "classical" turbidites (Walker 1984).

Sandstones are poorly sorted and usually range from litharenite to lithic wacke in composition. They are interbedded with dacitic crystal-rich tuffs of the upper unit of Cycle I. Beds range from 0.5 to 1 m thick and usually contain 70 to 90 percent subangular to subrounded grains of quartz and plagioclase identical in size, but better rounded than phenocrysts in adjoining pyroclastic units. In one area, sandstone beds were seen to pass laterally over about 100 m into crystal-rich tuffs. This transition is marked by progressive winnowing of fine-grained, sericitic felsic ash and a change in the degree of rounding of phenocrysts. No primary sedimentary or volcanic features were seen. Several discrete beds of quartzarenite to quartzwacke are present within this sequence. These are clearly epiclastic in origin, however, and likely also grade laterally into pyroclastic rocks.

Polymictic conglomerate beds 1 to 2 m thick are intimately associated with turbiditic units. They are chaotically sorted and consist of 10 to 30 percent clasts supported in a fine-grained garnet-biotite-bearing siltstone matrix. Clasts are variably subangular to rounded, and range in size from pebble to boulder. Identified clast lithologies include 80 to 90 percent reworked felsic to intermediate pyroclastic rocks, 5 to 10 percent mafic metavolcanic clasts, and <1 percent mudstone intraclasts.

Cycle II

Cycle II rocks form a mafic to felsic cycle similar to that of Cycle I; however, given the greater thicknesses of units, the cycle was divided into three parts. These are as follows:

1. a 30 m thick basal chemical sediment/pelite horizon (not shown on Figure 5.8)
2. up to 800 or 900 m of pillowed and massive mafic volcanic flows termed Cycle IIa; rare komatiite flows are present at the base of the unit
3. about 1000 m of felsic pyroclastic rocks and minor lenses of mafic volcanic rocks—these are referred to as Cycle IIb rocks

The base of Cycle II is marked along most of the length of the belt by a 20 to 30 m thick unit of interbedded pelitic wackes, iron formation and intermediate flows. This unit is traced from the Northeast Arm to Central Bay of McInnes Lake forming a distinctive marker horizon separating the two cycles. In the central part of the lake, this unit overlies Cycle I tuffs and sediments with an apparently conformable contact; however, in the northern end of the lake, the upper felsic unit of Cycle I is absent and the sedimentary horizon directly overlies the basal mafic metavolcanic unit of Cycle I. The iron formation in this unit is laterally continuous. In the north, it forms a thinly laminated chert-magnetite oxide-facies unit. This passes laterally into a garnet-actinolite-chlorite-chert silicate-facies unit in the central part of the lake. The transition from oxide- to silicate-facies iron formation takes place over about 1 km. This is marked first by the appearance of pods of silicate iron formation in the chert-magnetite unit. These become increasingly prevalent southward. Magnetite correspondingly becomes less prevalent until it finally disappears. Pelitic wackes and mudstones are interbedded with the iron formation. These contain either a garnet-biotite-plagioclase-quartz or a garnet-biotite-sillimanite assemblage. Commonly, beds are less than 20 cm thick but exhibit good primary grading. This allows reliable east to southeast younging directions to be obtained across the base of Cycle II.

Cycle IIa is a 50 to 800 m thick unit dominated by mafic metavolcanic rocks. The unit attains a maximum width between Power Bay and the Northeast Arm but thins rapidly northward and southward where it is only 50 to 100 m thick. In the Power Bay area, the thick sequence of pillowed and massive flows gives southeastward to eastward structural facing directions. The thickest part of Cycle IIa volcanic rocks here are directly west of the mafic dike swarm which cuts Cycle I rocks on the western shore of the lake. Flows are up to 40 m thick and usually pillowed. Pillows are commonly very large and can exceed 2 m in diameter. They commonly have well developed selvedges up to 15 cm thick and abundant interpillow hyaloclastite breccias have been observed. Most flows also contain up to 30 percent, 1 to 2 cm sized varioles which commonly cluster toward the rims of pillows. Mafic flows of Cycle IIa are commonly hornblende porphyroblastic, similar to the dike swarm in Cycle I. Some flows are also plagioclase-phyric, containing 1 to 5 percent of 5 to 7 mm sized, saussuritized plagioclase laths. In the Central Bay area, several variolitic ultramafic flows are seen immediately above the basal sedimentary unit. These 2 to 5 m thick flows contain a fine-grained tremolite-chlorite-talc assemblage. No primary flow textures, such as spinifex or polysuturing, were found. Mafic flows of Cycle IIa grade upward into intermediate and felsic pyroclastics in the Power Bay area and into massive intermediate flows in the Central Bay area.

Cycle IIb (Figure 5.8) rocks consist dominantly of felsic to intermediate pyroclastic rocks with minor lenses of mafic metavolcanics. As with Cycle I, pyroclastics here exhibit very well developed bedding and normal grading. All top indicators suggest a uniform east– to southeast–younging direction. Beds are usually from 0.1 to 10 m thick, and a positive correlation of bed thickness to grain size is observed. Multiple fining–upward sequences are present in the sequence. Commonly they consist of coarse pyroclastic breccia or tuff–breccia bases grading upward to finely laminated white tuff over about 30 m. Lithic fragments are both essential and accessory in origin. About 80 to 90 percent of these lithics are essential, but 10 to 20 percent consist of fragments derived from the underlying Cycle I and Cycle IIa volcanic rocks. The coarsest association and the thickest part of the sequence is once again located in the Power Bay area where lapilli–tuff to tuff–breccia dominate the pile. Laterally to the south, these give way to crystal tuffs and ash beds. The crystal tuffs are bedded on a 5 to 20 m scale and contain up to 70 percent angular quartz phenocrysts. Some flows also are plagioclase phyric. Pyroclastic rocks disappear entirely in the central area of McInnes Lake and Cycle IIb rocks consist entirely of thick (>10 m), massive intermediate flows.

Tuff beds are white to grey in colour and usually very fine grained. Although fine horizontal lamination is present in most beds, no surge or flow structures were observed. Tuff units vary from 0.1 to 1.0 m thick and are the first felsic rocks observed as discrete interbeds in the upper part of Cycle IIa.

Pelitic interbeds are common within the pyroclastic sequence, as are several units of turbiditic association. However, distinct sedimentary units such as occur in Cycle I are not present.

Toward the eastern margin of the greenstone belt, minor lenses of mafic rock were reported by Averill (1968) as gabbroic lenses. Cominco Limited subsequently reclassified these as of volcanic origin. These were not visited during this study and no further inferences are made.

Cycle III

On the southern part of the lake, a package of volcanic rocks consisting dominantly of felsic pyroclastics and minor mafic horizons is tentatively labelled as Cycle III. This unit is separated from Cycle I by well developed dextral shear zones (Figure 5.8) and contains a markedly different lithological makeup to that of Cycle I. However, Cycle III rocks are similar to those of Cycle IIb and, in the southern part of the belt, Cycle I and Cycle III rocks are west facing. This might suggest Cycle III may in fact be equivalent to Cycle IIb. The cycle is divisible into two units. These are a basal 800 to 1000 m thick dominantly felsic pyroclastic rock, and about 200 to 300 m of massive mafic flows and ash.

The basal unit of felsic pyroclastic rock is poorly preserved and only one west–younging top indicator was obtained. The felsic rocks are very fine grained, quartz and feldspar phyric, and thinly to very thickly bedded tuffs and crystal tuffs. Minor massive mafic flows and intermediate plagioclase–phyric ash flows are also present, but the bulk of the lower unit is of felsic composition.

An approximately 200 to 300 m thick unit of massive mafic volcanic flows and finely laminated mafic ash horizons conformably overlies this sequence. Unfortunately, penetrative deformation has destroyed much primary fabric and as with the underlying unit, only one facing direction was obtained.

Felsic Intrusive Rocks

Four distinct types of felsic bodies, variably pre– to late synkinematic, were seen in the study area (Figure 5.8). They are as follows:

1. Two bodies of deformed older tonalite to granodiorite gneiss located to the north, east, and southwest of the belt.
2. A synkinematic (two–mica)–garnet granite body and associated sheets located in the northern to central parts of the belt.
3. A relatively young body of synkinematic tonalite located on the western margin of the belt.
4. A small body of late synkinematic to postkinematic coarse–grained granite pegmatite located at the entrance to South Bay.

1. The granitoids bounding the belt to the north and east are both strongly deformed bodies. To the north they are interfolded with the supracrustal rocks, and to the south they have acted as a basement upon which the supracrustal rocks have been thrusted. Both bodies are potassic feldspar megacrystic to varying degrees. The intensity of potassic feldspar megacryst development is commonly related to proximity to granite, pegmatite, and aplite dikes injected parallel to gneissosity. These develop potassic metasomatic haloes which appear responsible for development of the megacrystic texture.

The body to the north is a distinctive inhomogeneous potassic feldspar megacrystic biotite monzogranite to granodiorite and exhibits a complexly interfolded boundary with the supracrustal rocks (Figure 5.8). Usually this body exhibits *lit–par–lit* injection into gneissic supracrustal rocks, which is then deformed and isoclinally folded by a subsequent event. As with all the local granitoids, potassic feldspar megacrysts appear to have been developed in a syntectonic to post–tectonic late–stage setting and are related to potassic metasomatism.

To the east, a large, potassic feldspar megacrystic to equigranular tonalite to granodiorite orthogneiss is interfolded with, and sheared along with, adjoining supracrustal rocks. In the Power Bay area, the body is gneissic, defined by biotite–hornblende segregations, and is strongly foliated to sheared with a dextral sense of movement. Late aplite and pegmatite dikes cutting the body are also strongly affected by this fabric. Thrusting along the contact in this area is strongly suggested by shallow, southwest- to west-dipping schistosity and downdip lineations. Farther south in the Central Bay and Southeast Bay areas, the body is strongly gneissic, with an intense isoclinal, north-oriented, similar style Z-folding of the fabric. *Lit-par-lit* injection of the body within the supracrustals as well as the supracrustals themselves, also exhibits a tight, north-oriented, Z-folding. Once again schistosity and parallel axial-planar fabric dips quite shallowly westward and lineations are downdip. Throughout the body, potassic feldspar megacrysts appear, at latest, syntectonic and contain many valuable kinematic indicators.

On the southwestern shore of West Bay, McInnes Lake, a similar type of body was observed. This also exhibits early gneissosity and late potassic feldspar megacryst development; however, fabric within this body is imposed by intrusion of the later tonalite immediately to the north of it. As a result, the relationship of this body to other older granitoids is uncertain.

2. In the centre of the triple junction of the northern part of the belt and along the eastern boundary of the belt, a small stock and associated sheets of very coarse grained (two-mica)-garnet granite pegmatite were observed. This small body in the triple junction is undeformed beyond a slight S-fabric development, and lineations within the enclosing supracrustals plunge toward it, suggesting a possible late tectonic emplacement. Sheets and dikes of similar material are found in the northeastern portion of the belt on the Power Bay narrows where they are intensely deformed by thrust fault imposed fabric. Other undeformed dikes of the same material are found close to the eastern and western margin of the belt, as far south as central West Bay (*see* Figure 5.8). These rocks contain a coarse quartz-potassic feldspar-plagioclase matrix assemblage with radial aggregates of muscovite-quartz-garnet-biotite infilling fractures and seams. Garnets appear randomly dispersed throughout the matrix as well as in association with the radial mica aggregates.

3. To the west, a relatively young body of biotite-hornblende tonalite to granodiorite intrudes the supracrustals, imposing a near-vertical fabric on all rock types. The body itself is only weakly deformed, and partially potassic feldspar megacrystic as the result of dike-induced potassic alteration. It is intruded by two-mica- (i.e. biotite-muscovite) garnet trondhjemite dikes. This young intrusion appears to enclose an older, metamorphosed, garnetiferous, potassic feldspar megacrystic body on the southern part of West Bay. This deformed body is essentially identical to granitoids bounding the belt to the east and contains strongly saussuritized plagioclase and chloritized hornblende.

4. In the Southeast Bay area, a lensoidal, roughly pear-shaped, undeformed, pegmatitic sheet contains multiple zonations of aplitic and graphitic pegmatitic bodies with 1 to 4 cm wide radial muscovite + tourmaline + actinolite (?) clusters in a granitic matrix. The body cuts across all regional fabric and is assumed to be postkinematic to late synkinematic.

METAMORPHISM

The McInnes Lake belt, on average, exhibits a significantly higher metamorphic grade than similar supracrustal belts in adjoining subprovinces. The dominant facies is lower to middle amphibolite, with mafic and intermediate bodies commonly containing a hornblende + plagioclase + garnet assemblage, and pelites containing a quartz + sericite + garnet + biotite assemblage. In the Power Bay area, Cycle I pelites were found to contain a garnet + biotite assemblage in the lower coarse-grained portions of beds and cordierite in the upper fine-grained portions.

The metamorphic grade appears to increase sharply adjacent to major shear zones and on the western margins of the belt, where pelites and fine-grained felsics contain garnet + biotite + sillimanite. On Central Bay, an enigmatic body possibly demonstrates migmatism with light-grey quartz + biotite + garnet restite (?) zones enclosed by anastomosing, white garnet + biotite + sillimanite paleosome (?) zones. Laterally, the sillimanite-rich zones become less prominent and only occur as pods and lenses of *in situ* mobilizate in bedded quartzites and pelites at the top of Cycle I. In the South Bay area, fine-grained felsic volcanic rocks adjacent to the main shear zone contain staurolite in addition to garnet + biotite + sericite.

STRUCTURAL GEOLOGY

The supracrustals and most adjacent granitoid rocks of the McInnes Lake area have been subjected to polyphase deformation and shearing (Table 5.1). Three distinct folding events are recognized, the first and most intensely developed of which involved isoclinal folding around north-trending axial planes. This F_1 event appears to have been produced by an intense northeast-oriented shortening which also gave rise to the low-angle thrusting of supracrustals onto granitoids on the western edge of the belt. Dextral movement along this shear is suggested by rolled potassic feldspars, bookshelf-type fracturing of potassic feldspars, dextral-shear bands, sinistral back rotation of boudinaged dikes, and by sinistral kinking. This, coupled with west to southwest, very shallowly (as low as 8°) dipping S-fabric and downdip lineations, gives a reverse (hanging wall up) sense of movement, indicative of thrusting. In some cases an earlier S-fabric was seen folded around F_1 folds in the supracrustals, and this, along with the folding of early gneissic fabric in the northern and eastern granitoids, seems to suggest that an earlier deformation had occurred.

TABLE 5.1. DEFORMATION EVENTS AND RESULTING FABRIC ELEMENTS MCINNES LAKE.

Phase	Fabric
D1	S1
D2	F1 S2, L2
D3	F2 S3, L3
D4	F3 S4

F_2 involved a phase of eastward-plunging, open, low-amplitude, high-wavelength buckling producing a variably absent to intensely developed crenulation of S_2 fabric. Mesoscopic warping of F_1 axial planes is also a direct result of the D_3 event.

A final D_4 event produced open southeast-trending and plunging F_3 folds which are only seen on the Northwest Arm of McInnes Lake and are not prominently developed. This possibly reflects a simple, late D_3 readjustment of principal stress axes or shear folding.

Shearing, with well displayed criteria for a dextral sense of movement, has played a major role in the development of the present configuration of lithologies. Most shear zones are axial planar with F_1 folds and in some cases exhibit open warping or, rarely, overprinting by S_3 crenulations. Many of these shears are mineralized and would make good potential exploration targets.

Intrusion of the younger, late kinematic body on the western margin of the belt has modified S_2 fabric such that a gradual steepening of fabric from east to west is seen, and, in some cases, reversals on lineation plunges across shear zones. In contrast, rocks in the South Bay area appear unaffected by this and may reflect simple synclinal folding around F_1-fold axes—further evidence for correlation of Cycle II and Cycle III.

Late brittle fracturing and east-oriented sinistral shearing have further readjusted lithological distribution to a minor degree, especially in the Central Bay to Power Bay Areas.

ECONOMIC GEOLOGY

Mineralization within the belt is largely related to sulphide zones within north-trending shears and is hosted by tuffs and fine-grained flows. However, on the Northeast Arm of the lake, an unreported, thick iron formation unit separating Cycles I and II has been isoclinally folded with development of mild to intense axial-planar shear. These shears have acted as the loci of grunerite(?) replacement of magnetite and sulphide mineralization, a similar setting to that of the Musselwhite Property on Opapimiskan Lake (Breaks *et al.* 1986), and thus a good target for gold exploration. Synvolcanic base metal mineralization was not observed in the belt, but the presence of extensive felsic piles interdigitated with mafic and andesitic flows does not preclude their presence. While carbonatized and/or serpentinized, most peridotite sheets do not appear to be mineralized.

CONCLUSIONS

Supracrustal rocks of the McInnes Lake Greenstone Belt represent cyclic mafic to felsic volcanism in which two and possibly three cycles are present. Cycle I and Cycle II represent typical greenstone volcanic cycles where a subaqueous mafic shield volcano is overlain by a felsic to intermediate volcanic edifice and associated epiclastic deposits (Ayres and Thurston 1985). In both cycles, the presence of coarse-grained facies rocks and a thickening of the pile in the Power Bay area suggest that the edifice was located there.

The contact between Cycle I and Cycle II appears conformable on outcrop scale, but the fact that the basal chemogenic unit of Cycle II is seen to overlie all units of Cycle I suggests that some form of unconformity is present. Erosion and reworking of the Cycle I edifice is also suggested by the presence of abundant epiclastic sedimentary units occurring laterally from the proximal facies near Power Bay. This is a common feature of old volcanoes in which most of the uplifted material is eventually removed to broad aprons surrounding the edifice (Ayres 1983).

The presence of pillowed mafic flows, well bedded and normally graded pyroclastic flows, the association of pyroclastic flows with sediment of turbiditic affinity, and the presence of chemical sedimentary horizons suggest that the activity took place in a subaqueous setting (Yamada 1984; Fisher 1977). The lateral transition of the chemical-sediment horizon at the base of Cycle II from oxide to silicate facies may possibly represent a lateral increase in water depth.

The similarities between many early gabbroic bodies, the dikes in the swarm cutting Cycle I rocks, and the flows in Cycle IIa suggest that these are all related and possibly represent a feeder system, subvolcanic magma chambers, and extrusive equivalents of the same system.

The localized occurrence of quartz-rich sediments in Cycle I is clearly related to epiclastic reworking of primary pyroclastic flows and does not suggest the presence of platformal-type sedimentation.

Although lacking a lower mafic volcanic unit, Cycle III is similar to Cycle II in many ways and is possibly equivalent. Alternatively, given the results of studies of similar volcanic cycles in the Uchi Subprovince (Wallace *et al.* 1986) it is possible that Cycle III could well be older than, or of intermediate age to, Cycles I and II. Results of geochronological studies underway should resolve this problem.

UPPER WINDIGO LAKE GREENSTONE BELT

LOCATION AND ACCESS

The Upper Windigo Greenstone Belt is located near the southern flank of the Sachigo Subprovince approximately 150 km northwest of the town of Pickle Lake and in the vicinity of Latitude 52°30′ and Longitude 91°30′. Access can be made either by float plane from Pickle Lake or by road (Highway 808) to Windigo Lake and thence upstream over a short section of rapids to Upper Windigo Lake.

PREVIOUS WORK

The presence of the Upper Windigo Lake belt was originally reported by J.B. Tyrrell (1913), and subsequently mapped in 1938 by G.M. Robson (Satterly 1941). Modifications to the map were made during subsequent reconnaissance surveys (Thurston *et al.* 1979; Sage and Breaks 1982).

GENERAL GEOLOGY

The greenstone belt rocks are adequately exposed in the western half of the belt to define the main units. The eastern half of the belt is poorly exposed owing to the presence of the Agutua Moraine overburden. The greenstone belt is dominantly composed of massive to pillowed basalt with interbedded units of iron formation apparent from linear magnetic patterns on aeromagnetic map 7013G (Ontario Department of Mines–Geological Survey of Canada 1963). Of the pillow lavas observed, only one exposure on an island in Upper Windigo Lake (Figure 5.9) provided a reliable determination of stratigraphic younging direction. Other younging determinations made from pillows, as previously reported by Thurston *et al.* (1979) and Sage and Breaks (1982) are not reliable. Two other units are described here: an intermediate to felsic pyroclastic unit and an epiclastic conglomerate unit. All rocks are metamorphosed from at least middle–greenschist to lower–amphibolite facies.

Intermediate to felsic metavolcanics

The pyroclastic unit (*see* Figure 5.9) was previously reported as epiclastic by both Satterly (1941) and Sage and Breaks (1982). This unit is tabular in form, extending for at least 22 km along strike, and is 500 to 750 m in width. It is principally composed of dacitic tuff to lapilli–tuff. The lapilli–tuff beds comprise ellipsoidal, angular clasts of chert and rhyolite in a dacitic matrix. Clasts are typically about 5 cm in length with some blocks up to 17 cm. The medium– to fine–grained tuff is consistently graded to the south or southeast. The lapilli–tuff shows both normal and reverse grading of clast size. Lapilli–tuff beds locally form well developed scours into underlying fine–grained tuff and confirm the southward–facing attitude of this stratigraphic unit.

The eastern end of this unit, on the northern shore of Upper Windigo Lake, is composed of sharply bedded quartz–plagioclase–phyric dacitic to andesitic tuff, lapilli–tuff, and volcanic conglomerate. One can observe both normal grading of grains in the tuff beds and reverse grading of chloritic clasts (possibly collapsed pumice). The massive conglomerate beds comprise a heterogeneous assemblage of clasts including dacite, rhyolite, chert, vein quartz, and gabbro and are interpreted as tuffaceous, matrix–supported to clast–supported, resedimented mass–flow units.

Clastic metasediments

Exposed on several islands along the length of Upper Windigo Lake is a clastic sedimentary unit flanked to the north and south by basaltic flows. This epiclastic package extends for over 7 km along the lake and may continue farther eastward under the overburden. It is dominantly composed of thinly to thickly bedded conglomerate with lesser wacke and arenite. The sedimentary sequence is probably less than 600 m thick. Figure 5.10 shows stratigraphic sections for three of the islands (*see* Figure 5.8) to illustrate the typical facies that characterize the entire sedimentary package and to illustrate the variation in dominant grain size or clast size between beds. The major facies are as follows:

1. massive, ungraded, sandy, matrix–supported to clast–supported conglomerate
2. graded, matrix– to clast–supported conglomerate
3. normally and lesser amounts of reversely graded bedded, clast– to matrix–supported conglomerate transitional to arenite or wacke
4. massive, ungraded sandstone (arenite or wacke)
5. normally and lesser amounts of reversely graded bedded arenite or wacke

An additional minor facies is laminated to massive siltstone/mudstone occurring on top of some sandstone beds.

The stratigraphic sections reveal sharply bedded conglomerate separated by thinner beds of sandstone (arenite or wacke) or beds grading transitionally from basal conglomerate to sandstone. Minor siltstone lies sharply above some arenite beds; in places, thin tabular siltstone clasts can be observed in the basal or mid–level portions of the coarser grained clastic units and may represent pieces of a former siltstone bed ripped up by rapid deposition of the new bed. Some of the sandstone beds taper out along strike and may be products of shallow channels. The conglomerate dominantly comprises angular to subangular clasts of various material, as shown by the modal analyses in Table 5.2. The clasts generally form approximately 30 to 70 percent of the rock in beds ranging from pebbly sandstones to con-

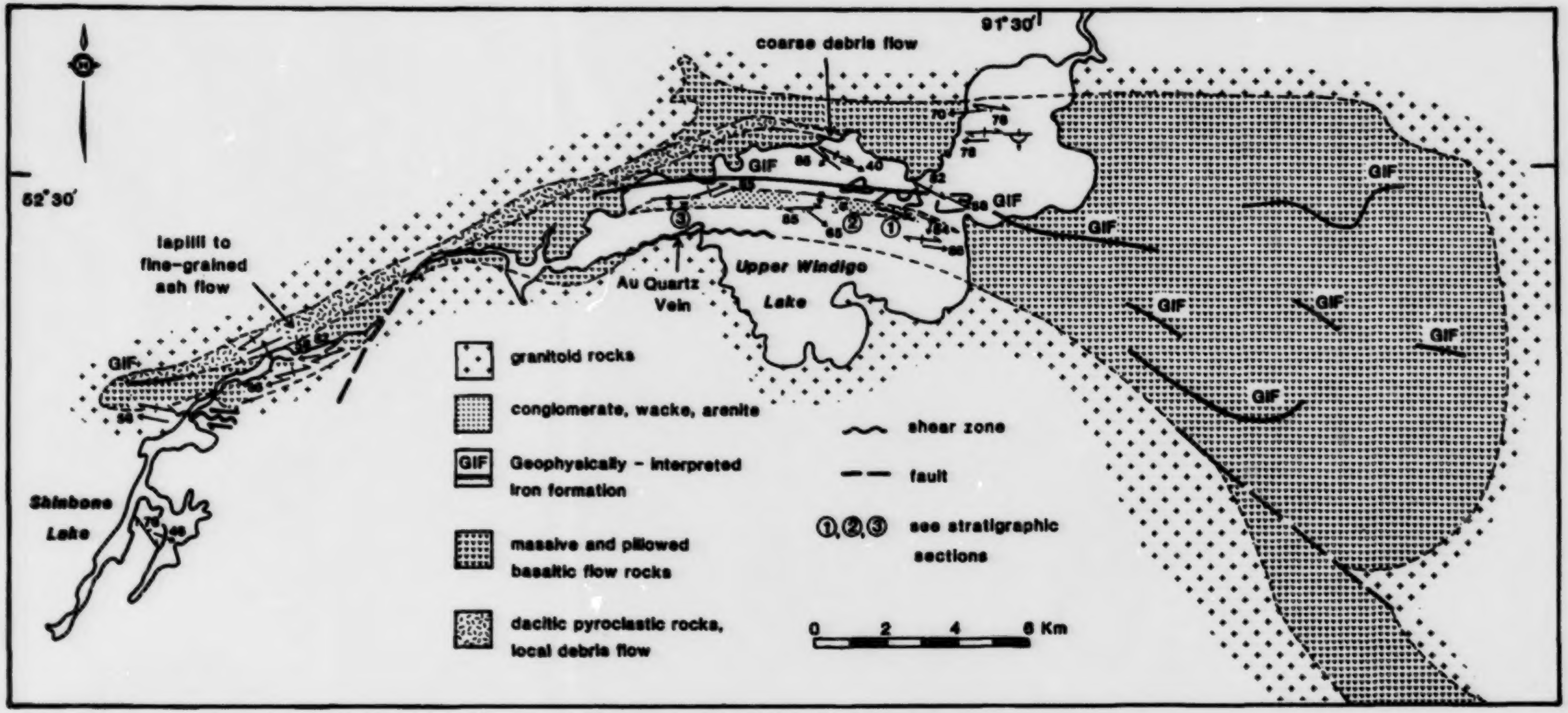
91°30′
52°30′
coarse debris flow
lapilli to
fine-grained
ash flow
GIF
Au Quartz
Vein
Upper Windigo
Lake
Shinbone
Lake
①
②
③
granitoid rocks
conglomerate, wacke, arenite
Geophysically - interpreted
iron formation
massive and pillowed
basaltic flow rocks
dacitic pyroclastic rocks,
local debris flow
shear zone
fault
①,②,③ see stratigraphic
sections
0
2
4
6 Km

Figure 5.9. *Geological map of the main part of Upper Windigo Lake Greenstone Belt, Sachigo Subprovince.*

TABLE 5.2. MODAL ANALYSES OF SANDSTONES.

	Location 2 %	Location 3 %
Matrix	31	29
White Chert	30	21
Red Chert	5	27
Black Chert	8	3
Rhyolite		2
Dacite	12	3
Andesite	1	
Basalt	2	
Schist		1
Quartz Arenite	3	
Quartz Porphyry	2	5
Quartz Feldspar Porphyry	2	1
Feldspar Porphyry	2	
Vein Quartz		3
Trondhjemite	2	5
	100 %	100 %

glomerates. The poor sorting of both matrix and clasts within individual conglomerate and sandstone beds and the angularity of the clasts define the textural immaturity of these rocks.

Bedding planes are flat with little evidence for channel gouging. In all three sections, the presence of grain–size grading in sandstone beds is variable and no cross–stratification is observed. Any original imbrication of clasts in conglomerate has been lost to rotation of clasts into a tectonic cleavage plane that is oblique to bedding.

In two outcrops on Upper Windigo Lake (1 and 2 of Figure 5.9), one can observe rare cobble and boulder size clasts (Photo 5.1) of mineralogically mature and texturally mature quartzarenite within conglomerate beds. The quartz grains in these clasts are rounded, coarse– to fine–grained sand size. At least one clast preserves the original grading of the quartz sand grains oblique to the long axis of the clast.

Similar internally graded quartzarenite cobbles were observed on the northeastern shore of Sachigo Lake in the Ponask–Sachigo Lakes Belt. The presence of these quartzarenite clasts in each belt suggests that a shallow–water depositional environment was exposed to erosion, either subaerial or submarine, the latter involving direct erosion by subaqueous channelling of the platform sequence.

DEPOSITIONAL ENVIRONMENT: DISCUSSION

This stratigraphic assemblage of coarse–grained clastic deposits can be compared with models of either alluvial fans and braided fluvial plains. (Rust and Koster 1984) or deep–water resedimented conglomerates associated with turbidites (Walker 1975). The 15 m sections in Figure 5.10 provide only a limited, two–dimensional window, but some pertinent comments are in order. In the easternmost sections (Section 1), thick, ungraded, disorganized conglomerate beds are most prominent with a greater occurrence of cobble and boulder size clasts than in the other two sections (i.e. 2 and 3). There is also a more common occurrence of inverse grading. Each of the sections features apparent cyclic sequences of conglomerate, sandstone, and siltstone. Relicts of the siltstone beds may be the rip–up clasts contained in the overlying conglomerate bed.

The facies represented in the stratigraphic sections appear to represent mass flow (debris flow) and channel deposits. The massive conglomerate and sandstone beds are due to rapid transport so that no traction developed to produce cross–stratification.

The stratigraphic assemblage comprises ungraded, disorganized, and inversely to normally graded beds with lack of cross–stratification, flat bedding planes, and the presence of laterally disrupted mudstone interbeds to form apparent turbidite couplets. This suggests that the sedimentary package developed within a channelway in the upper or proximal part of a submarine fan.

STRUCTURAL GEOLOGY

The Upper Windigo Lake (UWL) belt is a vertically dipping but consistently southward–facing panel of supracrustal rocks bounded to the north and south by granitic plutons. The southeasternmost extent of the belt has been determined from aeromagnetic patterns (Ontario Department of Mines–Geological Survey of Canada 1963) to extend discontinuously across a trondhjemitic pluton rich in amphibolite inclusions to the Horseshoe Lake belt. The western end of the Upper Windigo Lake belt appears to be on strike with and is probably correlatable with the McCoy Lake belt.

Right–handed, transcurrent shear zones are known to flank the Horseshoe Lake belt along its northern and southern margins (L. Jensen, Geologist, Ontario Geological Survey, personal communication, 1987). These shear zones appear to converge westward to form a zone that can be traced westward across the Pipestone River. This zone is interpreted to continue northwestwards and may follow at least part of the southern margin of the Upper Windigo Lake Greenstone Belt.

A protomylonitic shear zone at the northern end of Shinbone Lake occurs within trondhjemite close to the southwestern end of the Upper Windigo Lake Greenstone Belt. Another shear zone occurs on the southern shore of Upper Windigo Lake and hosts a 1 m wide quartz vein at the granite–greenstone contact. We have observed no other prominent shear zones within the Upper Windigo Lake Greenstone Belt.

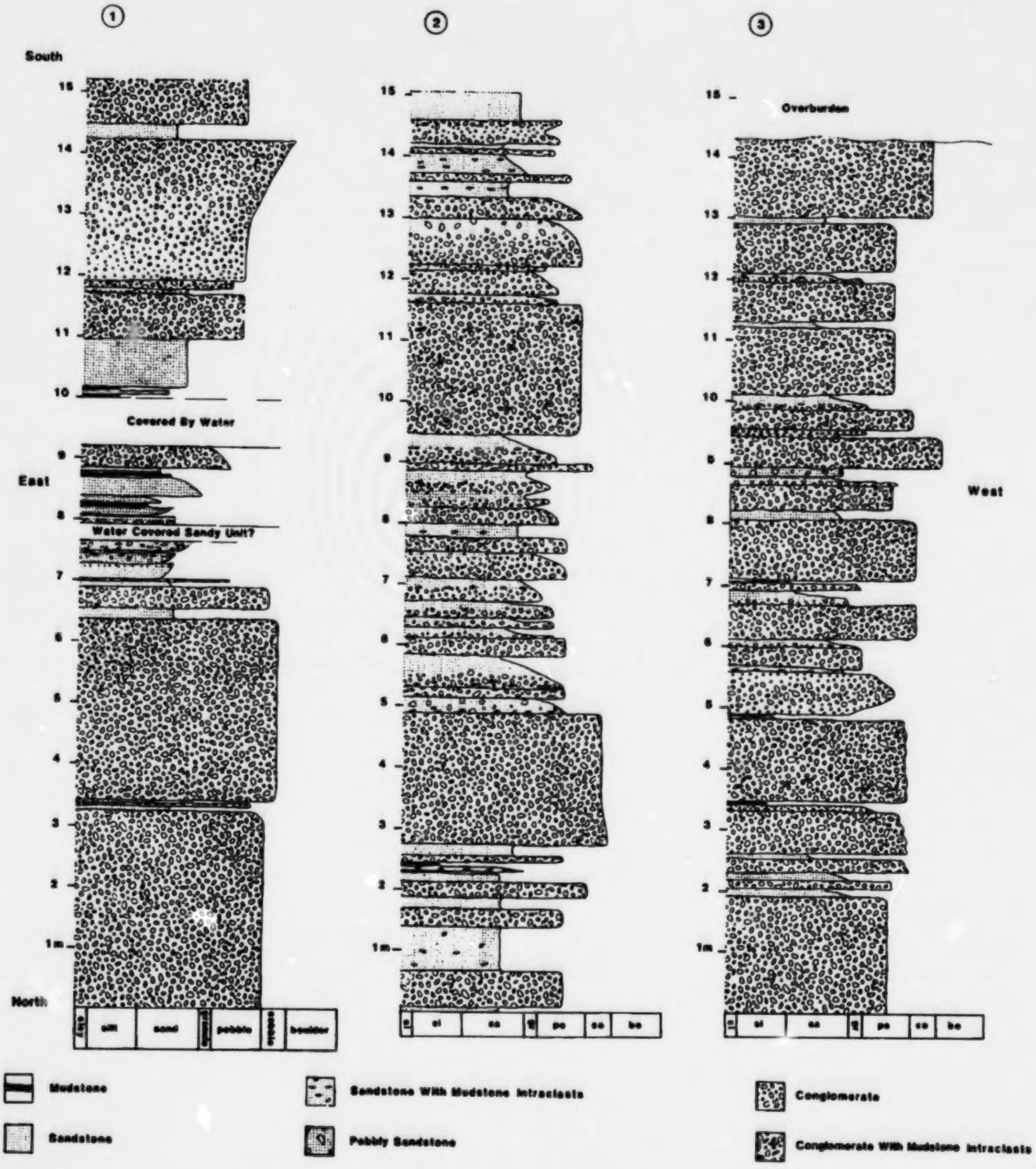
①
②
③
South
North
East
West
Covered By Water
Water Covered Sandy Unit?
Overburden
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1m
clay
silt
sand
granule
pebble
cobble
boulder
Mudstone
Sandstone
Sandstone With Mudstone Intraclasts
Pebbly Sandstone
Conglomerate
Conglomerate With Mudstone Intraclasts

Figure 5.10. *Stratigraphic sections from three locations shown in Figure 5.9.*

ECONOMIC GEOLOGY

The Upper Windigo Lake belt has been the subject of some recent gold exploration activity. The only historical note is a discovery about 60 years ago of a 1 m wide, milky white quartz vein on the southern margin of the belt (*see* Figure 5.9) that reportedly contains pyrite, chalcopyrite, and visible gold (Satterly 1941).

In view of the numerous major shear zones that are recognized along the margins of greenstone belts in the Sachigo Subprovince (Osmani and Stott, this volume), we speculate that the shear zone hosting the quartz vein is part of a shear/fault zone that continues southeastward to the Horseshoe Lake belt. The discovery of the Golden Patricia gold deposits by St. Joe Canada Incorporated (now Bond Gold Canada Incorporated), associated with a major

Photo 5.1. *Metamorphosed conglomerate with wacke sandstone bed under the scale, on Upper Windigo Lake (location 1, Figure 5.8). The two, large, rounded cobbles above the scale are composed of quartzarenite.*

shear zone along a greenstone–granite contact in Uchi Subprovince, encourages us to speculate that similiar deposits of that type remain to be discovered in this region. Further discussion is entered in Osmani and Stott (this volume).

HORNBY LAKE GREENSTONE BELT

INTRODUCTION

The Hornby Lake Greenstone Belt is located 150 km north of the town of Red Lake. It forms the most northerly sizeable mass of greenstone in the Berens River Subprovince. Access is via float–equipped aircraft.

During the 1988 field season, a total of five days were spent on the lake examining mineral occurrences and shoreline geology. Minor revisions to previous mapping (Ayres *et al.* 1973) were made and structural observations are included. Resedimented quartzarenite beds were identified on Findlay Lake.

GENERAL GEOLOGY

The western two thirds of the Hornby Lake Greenstone Belt (Figure 5.11) consists predominantly of mafic to komatiitic, pillowed to massive flows with subordinate intrusions of mafic to ultramafic composition. Minor lithologies include thinly bedded wacke, mudstone, and a sulphide–facies iron formation which outcrops east of Hornby Lake.

The peridotite intrusions are generally conformable to the volcanic strata and may have intruded as sill–like sheets. Along the northeastern arm of Hornby Lake, a thick intrusive unit changes in composition eastward from medium–grained, brownish–weathered peridotite to coarse–grained gabbro.

The eastern one third of the belt is well exposed on Findlay Lake. It is composed of sillimanite–bearing wacke locally interbedded with banded units of recrystallized chert and garnet–biotite wacke. In some places, beds of micaceous mudstone, lithic wacke, garnet–bearing quartzwacke and quartzarenite can be observed. The quartzarenite beds are graded and contain granule (Photo 5.2) to fine–grained sand sizes of quartz. Some quartz–rich beds contain varying amounts of mica, feldspar, and lithic grains and approach wacke composition. The metasediments are locally graded and generally folded.

We interpret the quartzarenite beds as resedimented sandstone deposited into a basin dominated by wacke turbidites. The presence of these quartzarenites suggests that platformal conditions had existed in the Berens Subprovince to permit the degree of sediment maturity necessary to concentrate quartz sands. This condition compares favourably with the widespread evidence for platform deposits in Sachigo Subprovince.

The western shore of Findlay Lake exposes a sequence of dacitic pyroclastic block and ash flows. The unit is less than 400 m thick and lies on top of the clastic sediments on Findlay Lake.

The western side of the Hornby Lake Greenstone Belt is in contact with a weakly foliated, medium–grained, inequigranular tonalite. This intrusion is a comparatively massive body and does not appear

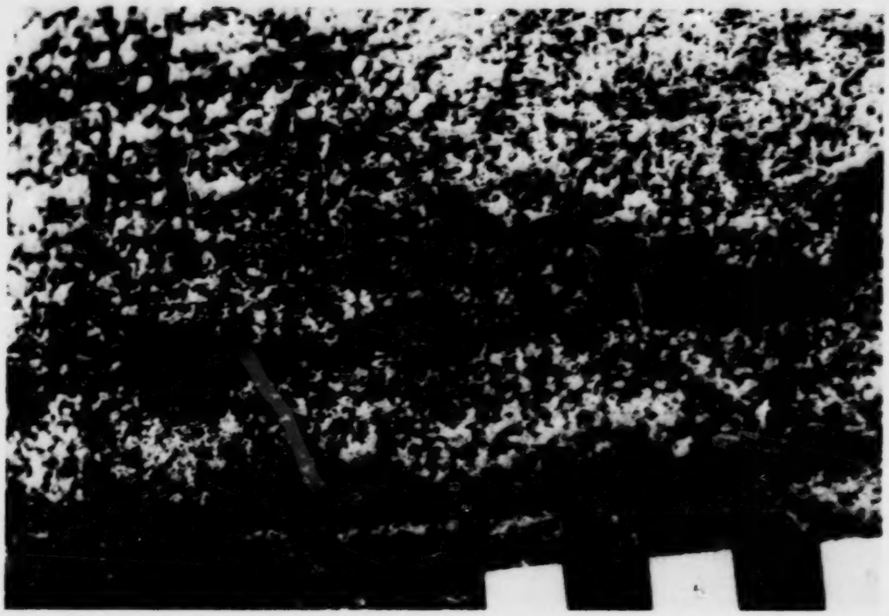

Photo 5.2. *Closeup view of very coarse sand and granule-sized quartz grains in a bed of quartzarenite. The graded bed is interlayered on Findlay Lake with sillimanite-bearing pelite.*

to be tectonized. The greenstone–batholithic contact can be traced along shoreline outcrops and on island outcrops in the lake.

The eastern margin of the greenstone belt is in contact with a strongly foliated fine– to medium–grained biotite tonalite. This tonalite body has been tectonized and conforms with the penetrative schistosity and mineral lineations in the greenstone belt. The strong deformation can be traced for 2 km eastward into the intrusion. Farther eastward, this east–bounding batholith is transitional to a weakly foliated, coarse–grained, potassic feldspar megacrystic, hornblende–biotite granodiorite.

STRUCTURAL GEOLOGY

The top indicators obtained in various parts of the greenstone belt suggest that the strata are locally opposite facing due to folding and/or faulting. The structural–facing direction (direction of younging of the folded strata) at Findlay Lake is to the southeast and apparently is facing away from the westward younging of graded dacitic tuffs on the western shore of the lake.

There is some evidence to suggest that faults occur along the margins of the sheet–like, mafic to ultramafic intrusions. Narrow shear zones, less than 30 cm wide, occur along the eastern contact of a gabbroic phase of one intrusion on eastern Hornby Lake. No associated veining or mineralization was observed.

The Hornby Lake belt is characterized by shallow, easterly dips of schistosity in the western half of the belt, and steeper, westerly dips in the vicinity of Findlay Lake toward the east. Easterly plunging, shallow–downdip hornblende lineations are very pronounced in the Hornby Lake area; but strong, more steeply plunging, southeasterly lineations characterize the rocks on Findlay Lake. The southeastern part of Hornby Lake exposes strongly amphibolitized mafic volcanics that record a complex, multiple deformational history, expressed as vein boudinage and refolded folds to form dome and basin structures.

The strong fabrics and contrast in lineation trends in different parts of the belt may reflect strain imposed by different plutons; namely, the large tonalite intrusion west of the belt and the pluton east of Findlay Lake.

The eastern metasediments can be traced as a long "tail" southwards between plutons and follows a prominent north–trending aeromagnetic pattern. This trend can be traced into the Uchi Subprovince toward the Red Lake Greenstone Belt. Our regional investigations show no structural break between the Uchi and Berens subprovinces apart from a gradational difference in depth of erosion.

METAMORPHISM

Adjacent to the batholithic contacts, basalts have undergone amphibolite–grade metamorphism and contain hornblende + plagioclase + garnet. The wacke metasediments at Findlay Lake are typically sillimanite–biotite–bearing units. A few other wacke beds are garnetiferous. Away from the batholiths within the centre of the belt, metamorphism is up-

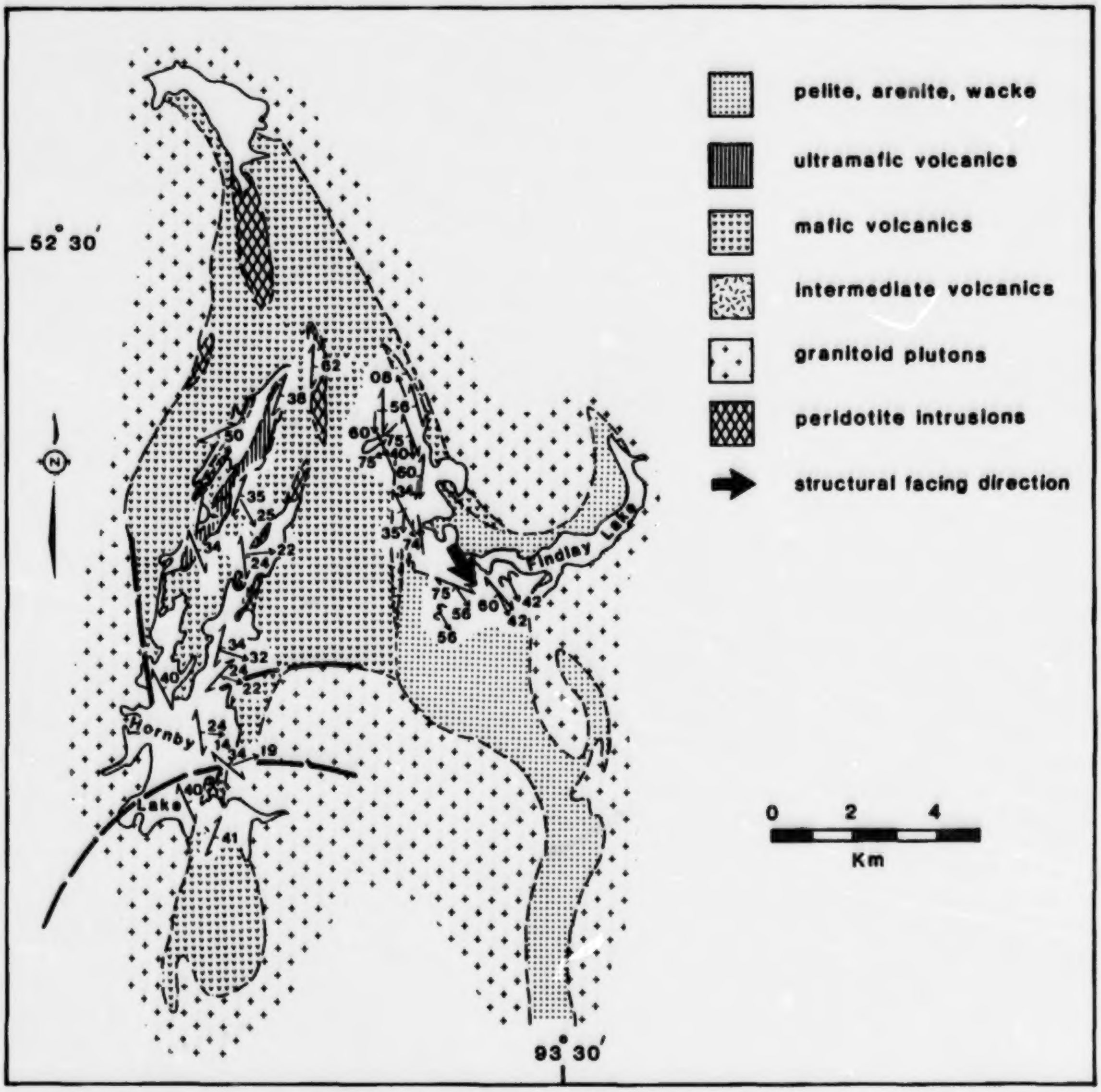
pelite, arenite, wacke
ultramafic volcanics
mafic volcanics
intermediate volcanics
granitoid plutons
peridotite intrusions
structural facing direction
52° 30′
93° 30′
N
Findlay Lake
Hornby
Lake
0
2
4
Km
62
38
50
08
56
60
75
40
60
34
35
25
22
24
74
34
32
24
22
40
24
14
34
19
40
41
75
56
56
60
42
42

Figure 5.11. *Geological map of the Hornby Lake belt, Berens Subprovince*

per–greenschist grade. Strongly deformed garnet porphyroblasts indicate peak metamorphism predated deformation.

ECONOMIC GEOLOGY

A significant, north–trending, sulphide–facies iron formation, several metres in width, outcrops to the east of Hornby Lake. The iron formation has received exploration interest from Asbestos Corporation Limited in 1970. Exploration included geophysical and geological surveys in addition to trenching, sampling, and limited diamond drilling. Low values in copper, nickel, and silver were reported by the company. Mineralization consisted of pyrrhotite with subordinate chalcopyrite.

In 1970, Coin Lake Gold Mines Limited, flew airborne magnetic, electromagnetic, and gamma–ray spectrometer surveys over a large area, including the northern half of the lake. Although, follow–up ground work was recommended, none was reported by the company.

No significant hydrothermal alteration was noted in the volcanic rocks. The narrow unit of coarse–grained, dacitic, pyroclastic rocks remains the only environment for potential massive sulphide mineralization.

PONASK–SACHIGO LAKES GREENSTONE BELT

GENERAL GEOLOGY AND STRUCTURE

The eastern end of the Ponask–Sachigo Lakes Greenstone Belt is composed of two lithostratigraphic sequences of metamorphosed sandstone and conglomerate exposed on the northern and southern shores of Sachigo Lake. These sequences are each enveloped to the north and south by massive to pillowed basaltic flows.

The metasediments generally comprise thickly bedded, massive, ungraded units of sandstone and conglomerate. The lithic/wacke sandstone beds of fine to medium and coarse sand sized grains are typically 3 to 6 m thick. They are interbedded with pebbly sandstone and conglomerate. Conglomerate beds vary in thickness from less than 1 m to more than 25 m thick. Clasts are subangular to subrounded and of dominantly pebble to cobble size. There is no clear size grading observed in the units. Local concentrations of tabular mudstone clasts occur within some conglomerate beds which may have been ripped up from interbedded mudstone units. The conglomerate beds typically contain clasts of chert, felsic and intermediate volcanics, felsic porphyry, minor granodiorite, quartz–feldspar arenite, and quartzarenite. The arenite clasts are cobble to pebble sized. One quartzarenite clast preserves within it an original bedding plane separating contrasting grain sizes of quartz. The few quartzarenite clasts are associated with felsic volcanic and quartz porphyry clasts. There are few granitic clasts.

Several units of mudstone and siltstone were observed. One is a dark–grey slate, 6 m thick and interbedded with conglomerate, occurring on the southern shore of Sachigo Lake.

The axis of a central anticline strikes east–southeastward along the length of the lake. This anticline separates the two metasedimentary sequences. The facing direction of the vertically dipping strata on the hinge of this anticline is to the west. The bedding dips vertically to steeply away from the axial plane of the anticline.

The schistosity strikes northeastward at an angle counterclockwise to the bedding on both the northern and southern limbs of the anticline. This schistosity therefore transects the anticline and is not symmetrical to it.

Mineral lineations and conglomerate clast elongations plunge typically 40° to 75° east–northeastward. The lineations plunge at angles oblique to the near–vertical hinge of the anticline and thus are neither parallel nor orthogonal to the regional fold axis.

The schistosity may reflect a regional–flattening event that postdates the anticlinal fold. Alternatively, it may reflect a northwesterly directed, transpressional deformation that produced both folding and the transecting schistosity. Evidence for northwest–directed shortening is widely observed as a late regional deformation in all subprovinces (Stott *et al.* 1987). Thus it becomes important to eventually establish the timing of regional folding and transecting schistosity and determine whether such deformation within the greenstone belts is related to the late northwest–trending shear zones observed along granite–greenstone contacts.

The typically thick, massive, ungraded beds of conglomerate and sandstone, with minor mudstone interlayers, comprise a general assemblage that closely resembles a similar sequence which may be observed at Upper Windigo Lake (*see* section "Upper Windigo Lake Greenstone Belt", this paper). We interpret the metasedimentary package to have been deposited by rapid transport in a channelway on the upper part of a submarine fan. The clastic material, apparently deposited by debris flow, was largely derived from felsic to intermediate volcanic sources and metasediments. The presence of quartzarenite cobbles in the massive conglomerate beds suggest part of the source area for clasts included a shallow–water platformal environment.

SUMMARY AND CONCLUSIONS

Major revisions to the boundaries of subprovinces of the Superior Province are becoming increasingly likely as a result of investigations of northern greenstone belts. The Sachigo Subprovince of Card and Ciesielski (1986) has been subdivided (W. Weber, Geologist, Manitoba Department of Energy and Mines, Winnipeg, personal communication, 1987) as follows:

1. Gods Lake domain: a granite–greenstone terrane extending from the Oxford Lake–Knee Lake–Gods Lake Belt east to the Big Trout–Nemeigusabins Belt in Ontario.
2. Molson Lake domain: granitoid and migmatitic rocks lying south of the Gods Lake domain. The block extends from Molson Lake to Winisk Lake, including the region between Stull Lake and Ponask Lake. The south boundary of the zone is the Ponask Lake Shear Zone (Osmani and Stott, this volume).
3. Island Lake domain: This granite–greenstone subprovince has been termed the Sachigo Subprovince by Ayres *et al.* (1971).

The speculation that the Gods Lake domain differs from the Island Lake domain by virtue of the absence of platform sequences has been strengthened by confirmation of the absence of platformal sequences at Ellard Lake and Swan Lake north and east of Stull Lake (Osmani and Stott, this volume).

The platform sequences within the Sachigo Subprovince are yet more widespread than was documented by Thurston *et al.* (1987), with new occurrences at Windigo Lake and the eastern part of Sachigo Lake. In the near future, we may be able to subdivide the platform–sequence–bearing greenstones into two types:

1. Sedimentary sequences derived from erosion of platform sequences such as the Keewaywin sequence, Sanborn Bay sequence (Thurston *et al.* 1987), and the Hornby Lake and Windgo Lake occurrences.
2. Platform sequences *sensu stricto*, such as the Keeyask sequence and the Zeemel–Pipestone–Heaton clastic sequence, both in the North Caribou Lake area (Bartlett *et al.* 1985; Breaks *et al.* 1986).

Platform sequences in the modern environment consist of shallow–water carbonates and quartzites (Sheridan 1974). The platform sequences of the Sachigo Subprovince are largely quartzarenite–bearing sedimentary packages. The most essential element of these packages is that they represent continued shallow–water deposition of basal quartzarenites and carbonates and probable shallow–water deposition of iron formation and overlying volcanic rocks—i.e. deposition kept pace with subsidence. This is in contrast to the mafic to felsic cyclical volcanism that is most common in greenstone belts (Ayres and Thurston 1985) where subsidence initially exceeds deposition. This relationship of subsidence versus depositional rate has led to speculation that carbonate sediments in the Uchi Subprovince represent platformal sequences (e.g. at Confederation Lake (Thurston and Chivers, in press)). We then have older greenstones in the Uchi, Berens River, and Sachigo subprovinces representing platformal deposition. There is some indication that there is no shear zone separating the Uchi and Berens River subprovinces; therefore, both structural and stratigraphic evidence suggests that the Berens River Subprovince may be a deeper erosional level of the Uchi Subprovince. More definitive evidence will be provided through geobarometric investigation.

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6. Project Number 88–23A. Regional–Scale Shear Zones in Sachigo Subprovince and Their Economic Significance

I.A. Osmani and G.M. Stott

Geologists, Precambrian Geology Section, Ontario Geological Survey, Toronto.

INTRODUCTION

This report is a product of a current program to revise the geological map of Ontario at a scale of 1:1 000 000. During the course of this work, many regional scale shear zones were defined, from aeromagnetic maps and some field checking, in the Sachigo Subprovince (*see* Figure 6.1 for outline of study area). Some of these zones, or portions of them, have been reported on previous compilation maps as faults or lineaments. Many gold occurrences are spatially associated with these shear zones, but few of these occurrences have been investigated to determine the nature of this association. This report presents a map of these regional shear zones, describes their geological and aeromagnetic characteristics, and discusses their economic significance.

Most of these structures have been divided, on the basis of scale, into fault zones (which are longer and more prominent) and shear zones (Figure 6.2); narrow zones of displacement are labelled faults and a shear zone previously named a deformation zone in the literature retains that label. All of

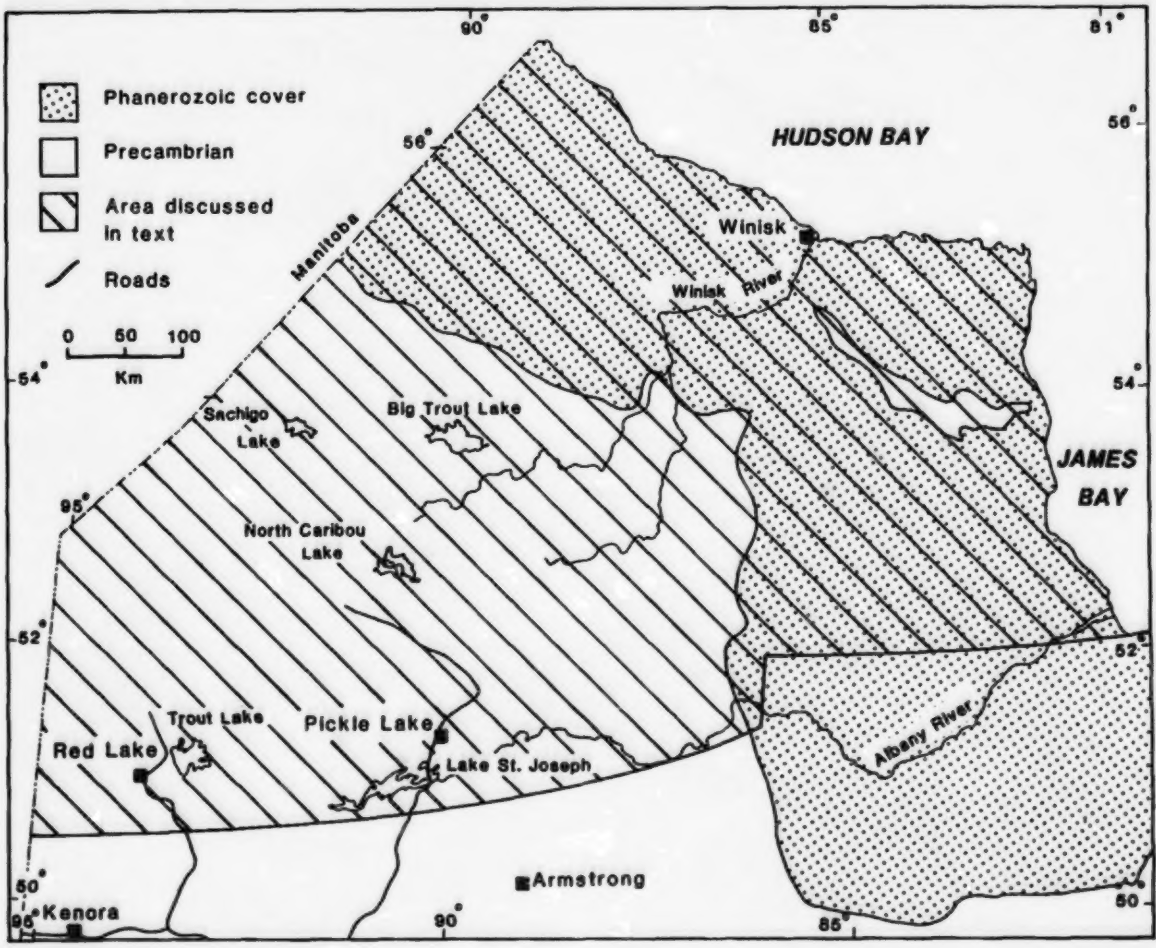
90°
85°
81°
56°
54°
52°
50°
95°
Phanerozoic cover
Precambrian
Area discussed in text
Roads
0 50 100
Km
HUDSON BAY
JAMES BAY
Manitoba
Winisk
Winisk River
Sachigo Lake
Big Trout Lake
North Caribou Lake
Trout Lake
Pickle Lake
Red Lake
Lake St. Joseph
Albany River
Armstrong
Kenora

Figure 6.1. *Location of the project area.*

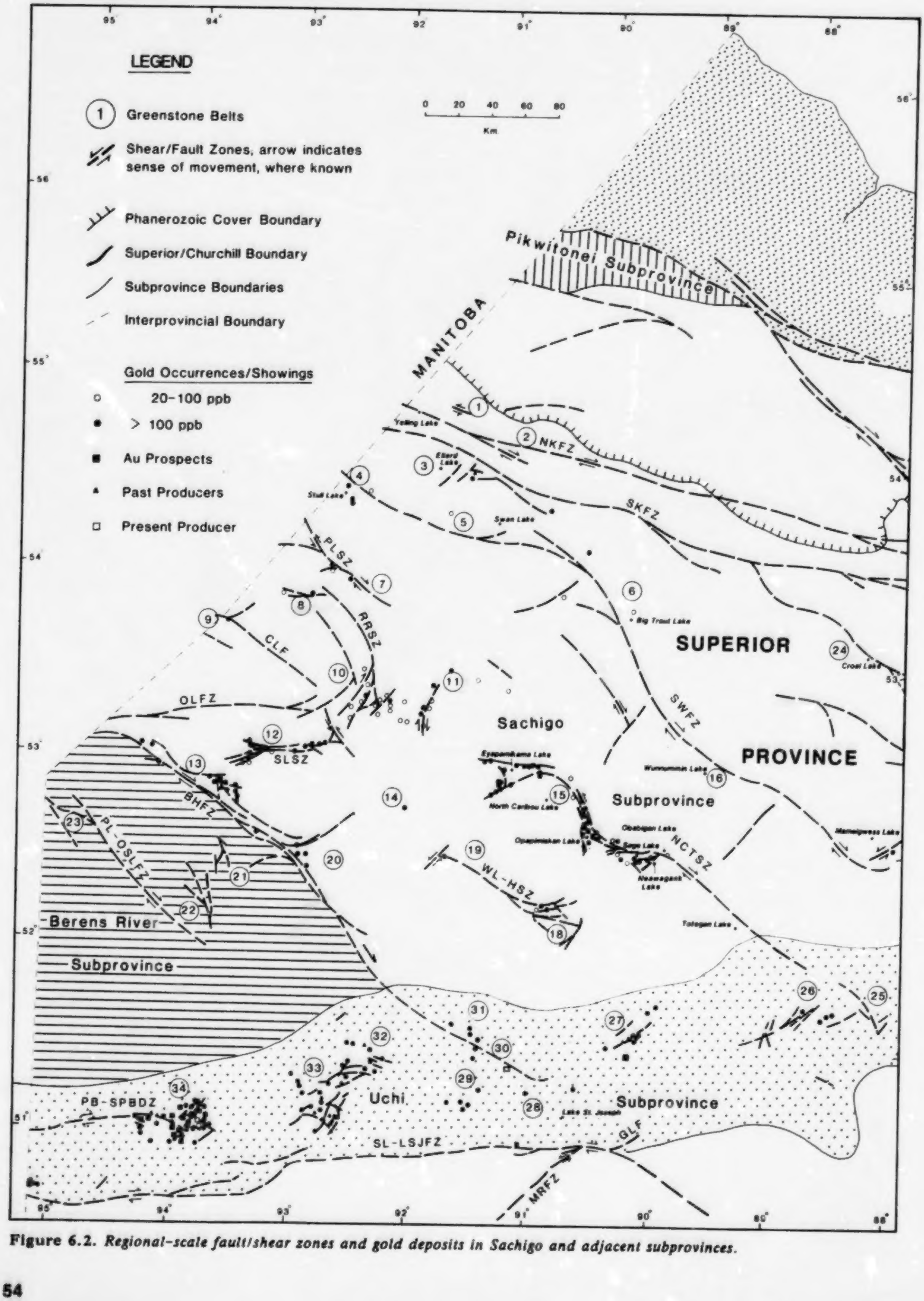
LEGEND
1 Greenstone Belts
Shear/Fault Zones, arrow indicates sense of movement, where known
Phanerozoic Cover Boundary
Superior/Churchill Boundary
Subprovince Boundaries
Interprovincial Boundary
Gold Occurrences/Showings
○ 20-100 ppb
● > 100 ppb
■ Au Prospects
▲ Past Producers
□ Present Producer
0 20 40 60 80
Km
95°
94°
93°
92°
91°
90°
89°
88°
56°
55°
54°
53°
52°
51°
Pikwitonei Subprovince
MANITOBA
SUPERIOR
PROVINCE
Sachigo
Subprovince
Berens River
Subprovince
Uchi
Subprovince
NKFZ
SKFZ
PLSZ
RRSZ
CLF
OLFZ
SLSZ
BHFZ
PL-OSLFZ
SWFZ
NCTSZ
WL-HSZ
PB-SPBDZ
SL-LSJFZ
GLF
MRFZ
Yelling Lake
Ellard Lake
Stull Lake
Swan Lake
Big Trout Lake
Croal Lake
Eyapamikama Lake
North Caribou Lake
Wunnummin Lake
Opapimiskan Lake
Obabigan Lake
Sage Lake
Neawagank Lake
Mameigwess Lake
Totogan Lake
Lake St. Joseph
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
18
19
20
21
22
23
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Figure 6.2. *Regional-scale fault/shear zones and gold deposits in Sachigo and adjacent subprovinces.*

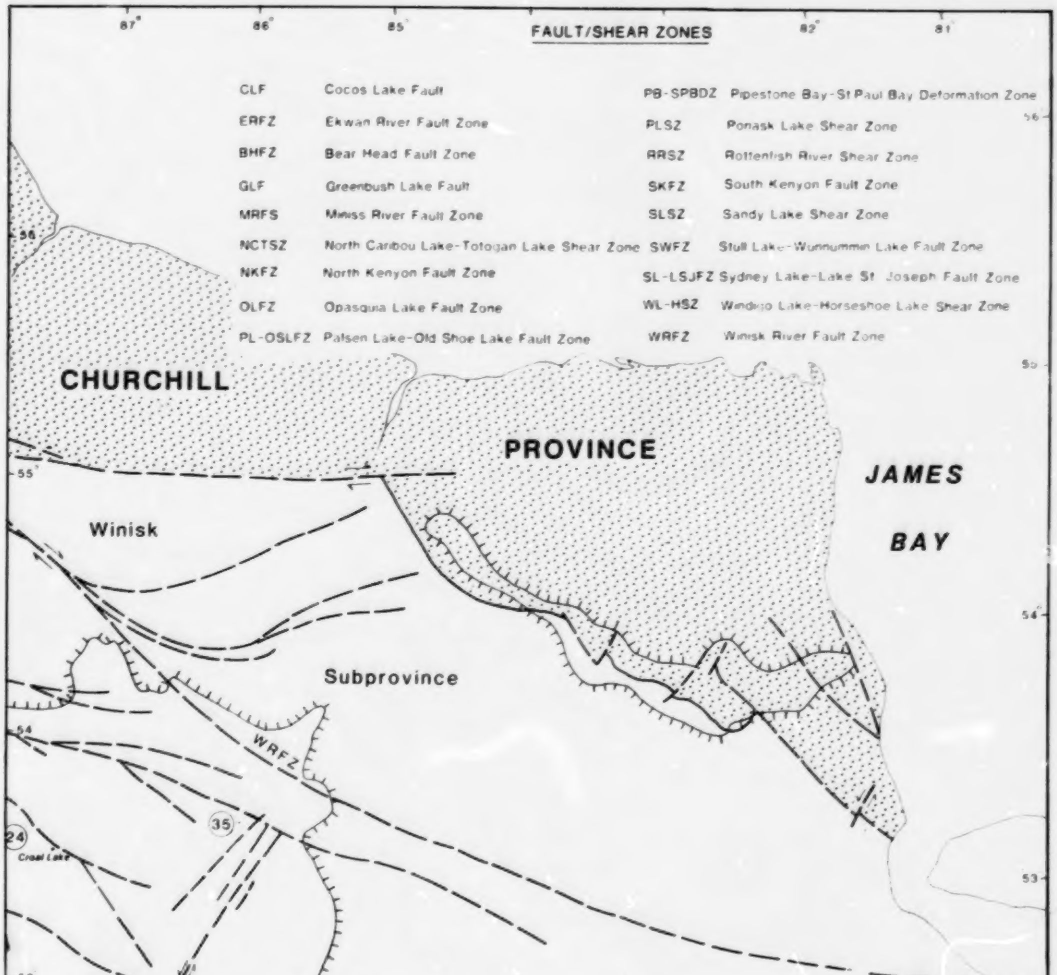
87°
86°
85°
82°
81°
FAULT/SHEAR ZONES
CLF Cocos Lake Fault
ERFZ Ekwan River Fault Zone
BHFZ Bear Head Fault Zone
GLF Greenbush Lake Fault
MRFS Miniss River Fault Zone
NCTSZ North Caribou Lake-Totogan Lake Shear Zone
NKFZ North Kenyon Fault Zone
OLFZ Opasquia Lake Fault Zone
PL-OSLFZ Palsen Lake-Old Shoe Lake Fault Zone
PB-SPBDZ Pipestone Bay-St Paul Bay Deformation Zone
PLSZ Ponask Lake Shear Zone
RRSZ Rottenfish River Shear Zone
SKFZ South Kenyon Fault Zone
SLSZ Sandy Lake Shear Zone
SWFZ Stull Lake-Wunnummin Lake Fault Zone
SL-LSJFZ Sydney Lake-Lake St Joseph Fault Zone
WL-HSZ Windigo Lake-Horseshoe Lake Shear Zone
WRFZ Winisk River Fault Zone
56
55
54
53
52
51
CHURCHILL
PROVINCE
JAMES
BAY
Winisk
Subprovince
WRFZ
ERFZ
24
Croal Lake
35
Mameigwess Lake
17
25
GREENSTONE BELTS
① Northern
② Thorne River-Sachigo River
③ Ellard Lake
④ Stull Lake
⑤ Swan Lake
⑥ Big Trout Lake
⑦ Ponask Lake-Sachigo Lake
⑧ Lingman Lake
⑨ Sagawitchewan
⑩ Rottenfish River
⑪ Muskrat Dam Lake
⑫ Sandy Lake
⑬ Favourable Lake-Azure Lake
⑭ Dawes Falls
⑮ North Caribou Lake
⑯ Wunnummin Lake
⑰ Mameigwess Lake- Rowlandson Lake
⑱ Horseshoe Lake
⑲ Upper Windigo Lake
⑳ North Spirit Lake
㉑ Hornby Lake
㉒ McInnes Lake
㉓ Cherrington Lake
㉔ Kasabonika Lake
㉕ Fort Hope
㉖ Miminiska Lake
㉗ Pickle Lake
㉘ Lake St Joseph
㉙ Bamaji-Fry Lakes
㉚ Meen-Dempster Lakes
㉛ Lang-Cannon Lakes
㉜ Birch Lake
㉝ Confederation Lake
㉞ Red Lake
㉟ Ekwan River
88°
87°
86°
85°
84°
83°
82°

Figure 6.2. *Continued.*

these zones are referred to as regional shear zones for ease of discussion. Many, if not all, have recorded both brittle and ductile displacements, but few have been the subject of detailed analysis (e.g. Stone 1981).

PREVIOUS WORK

Some of the shear zones were recognized many years ago. More recent workers, such as Park (1981) and Schwerdtner *et al.* (1979), have noted that these zones reflect an important northwesterly directed regional compression during the late Archean. They determined the orientation of the principal stress directions from the orientation of the shear zones and the displacements along them.

METHODOLOGY

Several shear zones not previously recorded in the Sachigo Subprovince have been identified, and the lengths of many others have been extended (Figure 6.2). This reinterpretation is based in part on recent mapping (Thurston *et al.* 1987; deKemp 1987; Wilson 1987; Breaks and Bartlett *et al.* 1986; Breaks *et al.* 1986, 1987; Bartlett *et al.* 1984; Stott 1985, 1986; Stott and Janes 1985); helicopter reconnaissance (Sage and Breaks 1982; Thurston *et al.* 1979; Bennett and Riley 1969); geochronology (deKemp 1987; Corfu and Wood 1986; Corfu *et al.* 1985); and some field checking by the authors during the 1988 field season. Interpretation of airborne magnetic (ODM–GSC 1963a to 1963g inclusive, 1967a to 1967i inclusive, 1968a, 1968b, 1969a to 1969e inclusive, 1970a, 1970b; OGS 1985) and gamma ray spectrometry maps (OGS–GSC 1977a, 1977b, 1978a to 1978d inclusive, 1979a, 1979b) was also used in this work.

The major features of the reinterpretation are 1) revision of the extent of some greenstone belts; 2) definition of new lithostratigraphic associations in some greenstone belts, i.e. an older (2850 to 3023 Ma) shallow water sequence and relatively younger (2750 to 2700 Ma) mafic to felsic volcanic cycles (Thurston *et al.* 1987; deKemp 1987; Wood *et al.* 1986); 3) recognition of new subdivisions of Archean granitoid rocks, based on a revised legend for a new edition of the geological map of Ontario (*see* Thurston, this volume); and 4) recognition of several large scale shear zones, which are potentially important targets for gold mineralization in the area.

Federal/Provincial aeromagnetic maps of the study area (ODM–GSC 1963a to 1963g inclusive, 1967a to 1967i inclusive, 1968a, 1968b, 1969a to 1969e inclusive, 1970a, 1970b; OGS 1985) show large scale magnetic features (compare Figures 6.2 and 6.3) that highlight: the correlation of chains of greenstone belts separated by plutons rich in amphibolite inclusions; the contrasting phases of different plutons; and most notably, faults and shear zones.

Shear zones are recognized by: 1) contrasts in magnetic patterns on either side of a linear anomaly; 2) truncation of lithological units and magnetic anomalies; 3) rotation of magnetic anomaly trends (which are comparable to foliation trajectories); and 4) long, linear zones of either low or high magnetic intensity. On the basis of these magnetic features, several shear zones of regional significance were identified (Osmani, in preparation). Some of these structures have been recently verified by field mapping by the authors; other structures remain to be checked in the future.

BEAR HEAD FAULT ZONE

The Bear Head Fault Zone (BHFZ) (Ayres *et al.* 1973) is approximately 515 km long and can be traced from near Lake Winnipeg in Manitoba eastward into Ontario, where it terminates along the northern boundary of the Meen–Dempster Lakes Greenstone Belt (Number 31, Figure 6.2).

The extent of this fault zone was recognized during the 1988 field season. The fault zone is characterized on the aeromagnetic maps by a narrow linear zone of high magnetic intensity. Several lake and river transects were examined across this zone between North Spirit Lake (Number 20, Figure 6.2) and the Meen–Dempster Lakes Greenstone Belt. Where the zone crosses plutons of hornblende-bearing potassic feldspar megacrystic monzogranite to granodiorite, the linear signature of high magnetic intensity is most pronounced. The hornblende has been altered during the deformation to magnetite, chlorite, and epidote. These rocks have been deformed to protomylonites with local very fine grained mylonite bands. Mineral lineations and the long axes of mineral aggregates are subhorizontal near MacDowell Lake, southeast of North Spirit Lake. Along the shear zone towards the Meen–Dempster Lakes belt, the lineations typically plunge 5 to 30° to the southeast. The detailed geometry, on a horizontal surface, of the protomylonite (Photo 6.1) shows a progressive clockwise rotation of the schistosity plane (S) towards the shear plane (C). These structures, which are reliable shear criteria (Berté *et al.* 1979), demonstrate a right-handed sense of shear. In addition, ductile shear bands and asymmetric pressure shadows of porphyroclastic potassic feldspar megacrysts complement this interpretation.

This fault zone is approximately 3 km in width on MacDowell Lake and southeast towards Cat Lake, and narrows progressively toward Meen Lake. North of Meen Lake, it appears to consist of several shear zones. Further southeast, the zone varies in width from 1 km on Wright Lake to 500 m on Kawinogans Lake (Stott and Wilson 1986).

In several locations within the Meen–Dempster Lakes Greenstone Belt, notably near Meen Lake

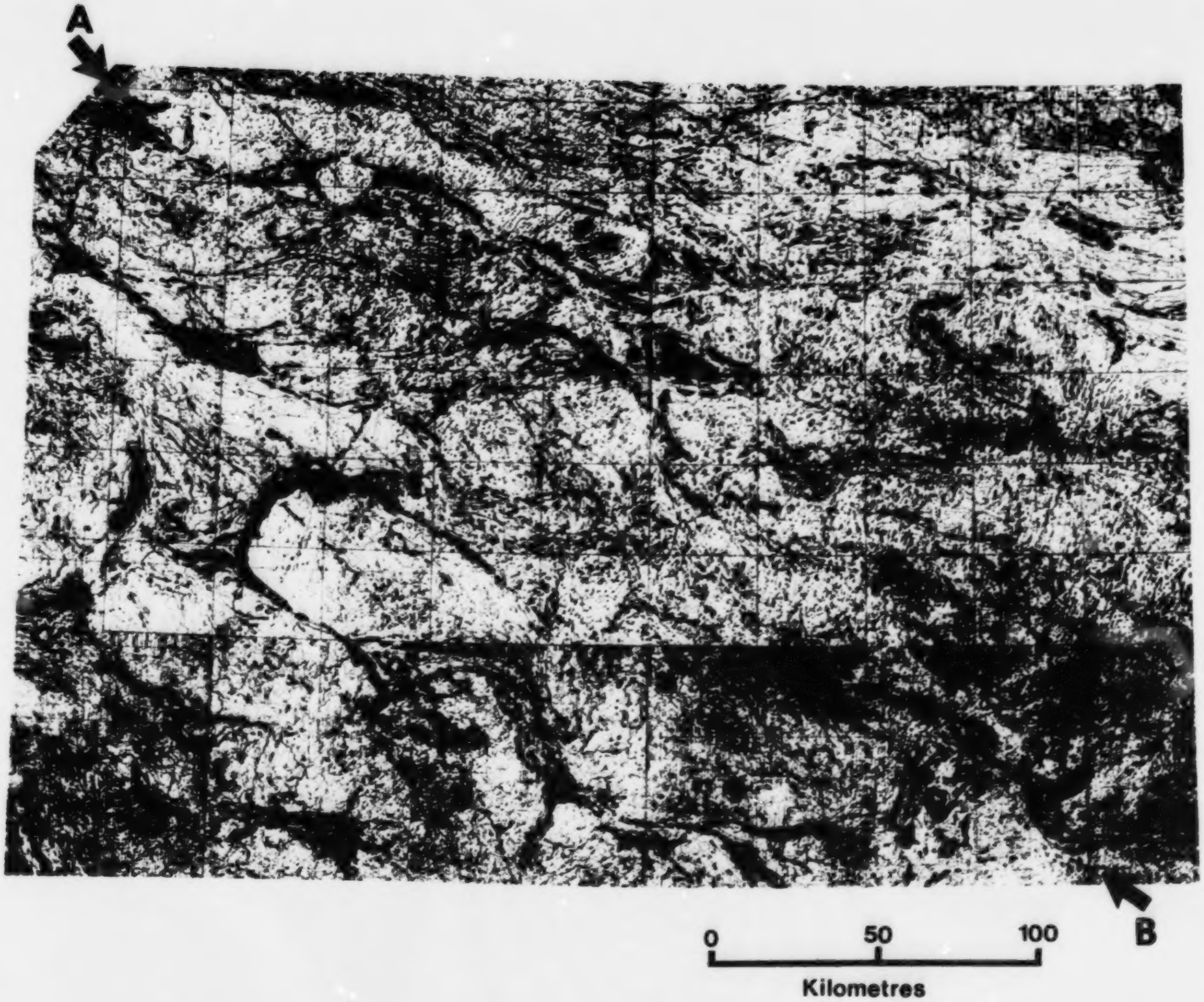

Figure 6.3. *Regional aeromagnetic compilation map taken from Maps P.575 and P.576 (ODM-GSC 1970a, 1970b). Letters A and B locate the Stull Lake-Wunnummin Lake Fault Zone. Compare with Figure 6.2.*

and north of Muskegsagagen Lake (Stott and Wilson 1986), narrow shear zones have been recorded. These zones are within several hundred metres of the granite–greenstone contact where the main Bear Head Fault Zone occurs. Locally, there is evidence in these zones for a right-handed sense of shear (Photo 6.2) and subhorizontal lineations of mineral aggregates. Such features of these narrow zones, which are typically less than a few metres wide, suggest that they are related to the main Bear Head Fault Zone.

ECONOMIC GEOLOGY

In December of 1985, the Golden Patricia gold deposit was discovered north of Muskegsagagen Lake in the Meen–Dempster Lakes belt by St. Joe Canada Incorporated (now Bond Gold Canada Incorporated). The deposit is now an active producing mine with reserves of 367 650 tonnes grading 20.47 g/t gold (0.596 ounce gold per ton) (The Northern Miner 1988). The gold occurs within and along the margins of a long sheetlike microgranular quartz vein, which is typically less than 1 m wide and can be traced along strike for over 3 km. The vein is sheared and locally folded. It lies within very fissile basaltic host rock and is bifurcated locally by less intensely deformed rock of the same host. The vein lies close to the northern margin of a long continuous quartz–phyric felsite unit (Stephenson 1986).

DISCUSSION

Regional and local observations in the Meen–Dempster Lakes belt (Stott and Wallace 1984; Stott

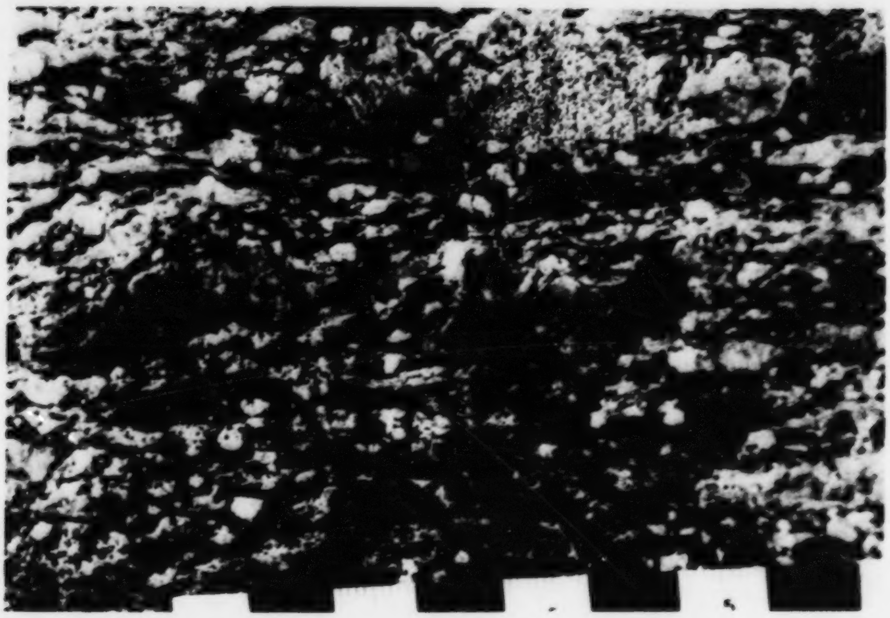

Photo 6.1. *Potassic feldspar–megacrystic monzogranite subjected to right–handed simple shear in the Bear Head Fault Zone. Right–handed sigmoidal asymmetry of local schistosity rotated into shear planes and rolled potassic feldspar augen highlight the sense of movement. Photo taken at Kamungishkamo Lake, west of Cat Lake. Centimetre scale at bottom.*

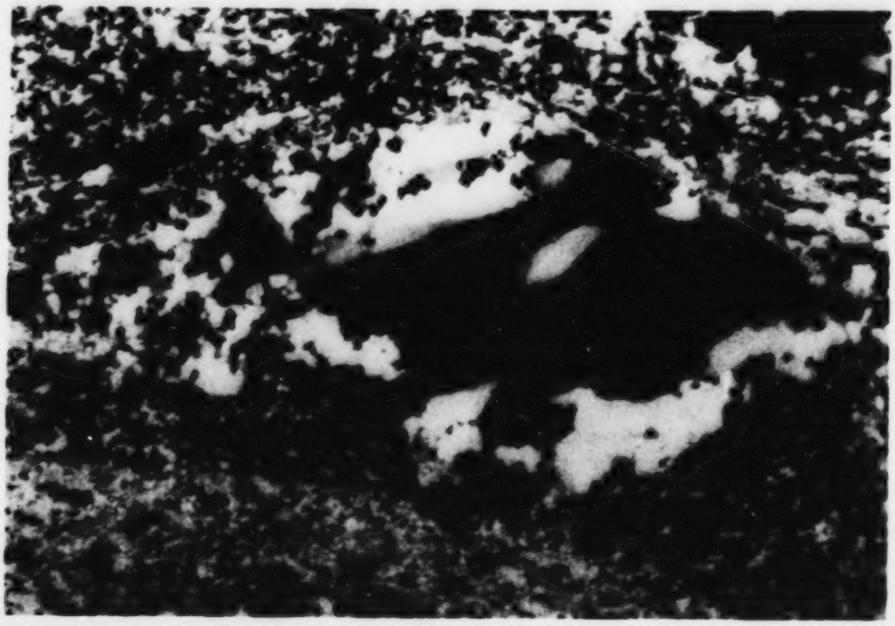

Photo 6.2. *Photomicrograph of a deformed quartz phenocryst in the sheared quartz porphyry unit that parallels the quartz vein of the Golden Patricia Mine. The quartz lens bears internal strain shadows as deformation bands, surrounded by serrated quartz subgrain growth. The shape asymmetry and tails of the quartz lens and the orientation of deformation bands are products of the right–handed sense of movement in the shear zone. Crossed nicols, 32x magnification.*

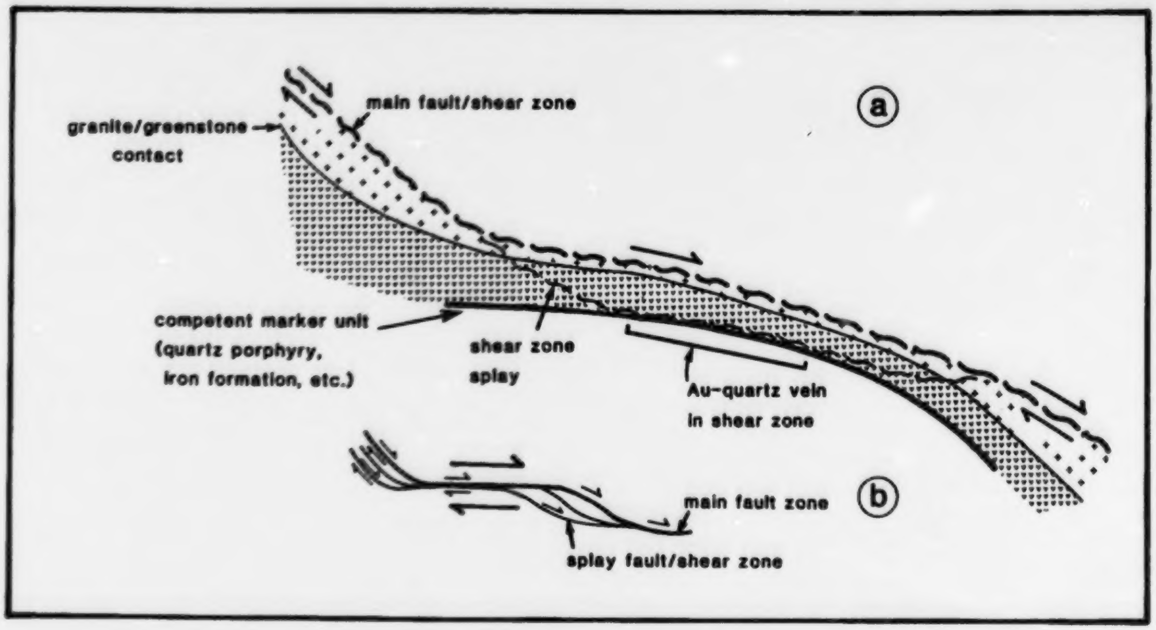
main fault/shear zone
granite/greenstone contact
a
competent marker unit (quartz porphyry, iron formation, etc.)
shear zone splay
Au-quartz vein in shear zone
main fault zone
b
splay fault/shear zone

Figure 6.4a. *A typical fault/shear zone following a northwest-trending granite-greenstone contact. A shear zone splays off the main zone and follows a competent lithological unit in the greenstone belt. The shear zone hosts a gold-quartz vein alongside the competent unit. The 3 km long quartz vein of the Golden Patricia Mine, near the Bear Head Fault Zone, is interpreted to exemplify this scenario.* **Figure 6.4.b.** *An idealized illustration of the asymmetric geometry of splay shear zones in relation to a main zone of right-handed transcurrent movement.*

1987) suggest that the BHFZ is accompanied by several narrow shear zones in the greenstone belt. These shear zones may be secondary splays or horsetails off the main zone at the granite–greenstone contact, similiar to fault patterns described by Granier (1985) and other workers (*see* Figure 6.4). It appears that a strike–slip fault/shear system will tend to follow the granite–greenstone contact. Where the contact is arcuate, the main fault zone will bend and follow (approximately) the contact. However, the trends of the main fault zone and granite–greenstone contact are not always parallel. In the vicinity of the Golden Patricia Mine, for example, evidence from the map pattern of shear zones invites the suggestion that the BHFZ may locally form an array of strike–slip imbricate faults that splay off the main fault zone into the greenstone belt. These shear zones tend to follow the strike of both bedding and schistosity that parallel the trend of the greenstone belt. These shear zones may terminate within the belt, or rejoin the main fault zone, as shown in Figure 6.4a. The search for an array of faults that splay off the main fault may be most profitable near a granite–greenstone contact that changes strike dramatically, as it does in the vicinity of the Golden Patricia Mine. Here, there is a greater likelihood that the main fault zone may relay splay faults into the greenstone belt, as in the idealized pattern shown in Figure 6.4b. This figure also shows the asymmetry of the fault/shear zone array in relation to the main right–handed strike–slip fault zone.

Similar fault/shear zone patterns may be anticipated in the vicinity of the other regional strike–slip fault zones that closely follow the east– and southeast–trending granite–greenstone contacts.

WINDIGO LAKE–HORSESHOE LAKE SHEAR ZONE

Aeromagnetic Map 7013G (ODM–GSC 1963f) shows a discontinuous arcuate chain of greenstone belts that includes the Horseshoe Lake and Upper Windigo Lake belts (Numbers 18 and 19, respectively, Figure 6.2). The Horseshoe Lake belt is dominated by an east–plunging (30°) anticline, flanked to the north and south by right–handed strike–slip shear zones, with the shear direction in each zone plunging 30° to the east (Jensen 1987). The two shear zones appear to converge west of the belt and are interpreted to continue as a single zone along the southern flank of the Upper Windigo Lake Greenstone Belt. The western extent of this shear zone has not been established, although there is some evidence for shearing at the granite–greenstone contact on the south shore of Upper Windigo Lake, where a gold–bearing quartz vein has been prospected (Satterly 1941).

NORTH CARIBOU LAKE–TOTOGAN LAKE SHEAR ZONE

A shear zone may be revealed by the deflection of regional magnetic trajectory lines into the shear zone direction. Such changes in magnetic trends are noted between Obabigan and Totogan lakes. West of Obabigan Lake, this structure converges into the shear zones of the North Caribou Lake Greenstone Belt (Bartlett *et al.* 1984; Breaks *et al.* 1986, 1987, in preparation; Piroshco 1986) to form the "North Caribou Lake—Totogan Lake Shear Zone" (NCTSZ).

On Totogan Lake, the NCTSZ transects a potassic feldspar megacrystic monzogranite. Mineral and dimensional lineations are subhorizontal. The potassic feldspar augens are rounded, with tails, and some are rolled (Photo 6.3). These features, plus a clockwise rotation of schistosity into the shear planes, confirm that transcurrent right-handed movement has occurred.

Gold mineralization within the North Caribou Lake belt mainly occurs in the following settings:

1. in fold noses (Hall and Rigg 1986) (Figure 6.5), where the quartz–pyrrhotite veins formed parallel to F2 axial planar cleavage at Opapimiskan Lake (Hall and Rigg 1986; Breaks *et al.* 1986, 1987), and Graff Lake (Breaks *et al.* 1987)
2. along sulphide-mineralized D2 shear zones at Libert, Neawagank, and Opapimiskan lakes (Breaks *et al.* 1987), the Randall Lake Property, and Eyapamikama Lake (Bartlett *et al.* 1984; Piroshco 1986; Piroshco and Shields 1985; Hodge *et al.* 1987) (Figure 6.6)
3. in quartz ± carbonate ± sulphide veins within or adjacent to shear zones in the Opapimiskan, Sage, and Eyapamikama lakes area (Breaks *et al.* 1987; Piroscho 1986), and at the Randall Lake Property (Figure 6.6) (Hodge *et al.* 1987)

The NCTSZ appears to continue southwards to the Keezhik Lake Greenstone Belt (north of Miminiska Lake, Number 26, Figure 6.2) and follows the northeastern margin of the belt. Long continuous units of banded iron formation also closely follow the northeastern margin of the belt. Accordingly, the potential for shear zones to splay from the NCTSZ into the belt and follow a competent lithological unit should be considered.

STULL LAKE–WUNNUMMIN LAKE FAULT ZONE

The Stull Lake–Wunnummin Lake Fault Zone (SWFZ) can be seen on the aeromagnetic maps to extend from Manitoba across northwestern Ontario between Stull Lake and Mameigwess Lake. This northwest-trending sigmoidal fault/shear zone is approximately 430 km long in Ontario. It is characterized by a distinct long linear magnetic anomaly of low to moderate intensity and closely follows the granite–greenstone contact along a string of greenstone belts. In a few locations, linear magnetic features are rotated into parallelism with the shear

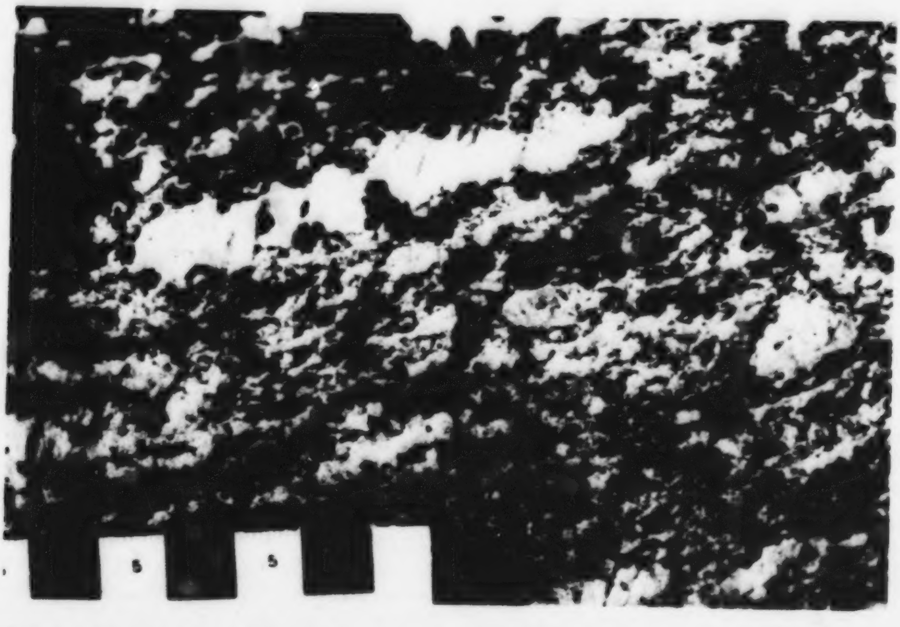

Photo 6.3. *Potassic feldspar-megacrystic monzogranite in the right-handed transcurrent North Caribou Lake-Totogan Lake Shear Zone. Partially lichen covered (black) outcrop shows rounded potassic feldspar augen with tails. Stretched augen at top contains reversed left-handed fractures induced by bulk right-handed shear.*

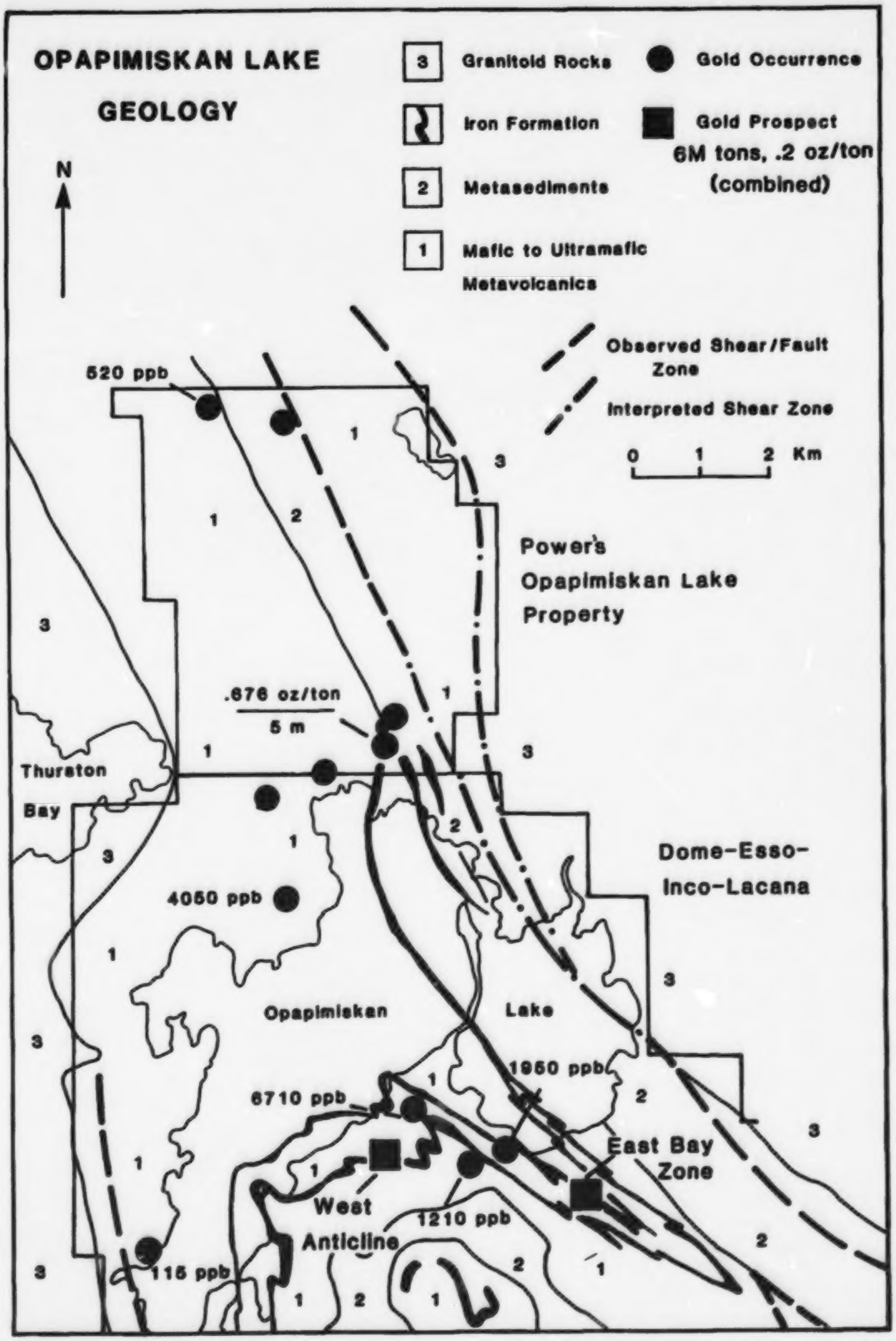
OPAPIMISKAN LAKE
GEOLOGY
3 Granitoid Rocks
Iron Formation
2 Metasediments
1 Mafic to Ultramafic Metavolcanics
Gold Occurrence
Gold Prospect
6M tons, .2 oz/ton (combined)
Observed Shear/Fault Zone
Interpreted Shear Zone
0 1 2 Km
N
520 ppb
Power's Opapimiskan Lake Property
.676 oz/ton
5 m
Thurston Bay
4050 ppb
Dome-Esso-Inco-Lacana
Opapimiskan
Lake
1950 ppb
6710 ppb
East Bay Zone
West Anticline
1210 ppb
115 ppb

Figure 6.5. *Geology and gold deposits at Opapimiskan Lake and the North Caribou Lake Greenstone Belt. Most gold deposits in this area bear no relation to the major shear/fault zones.*

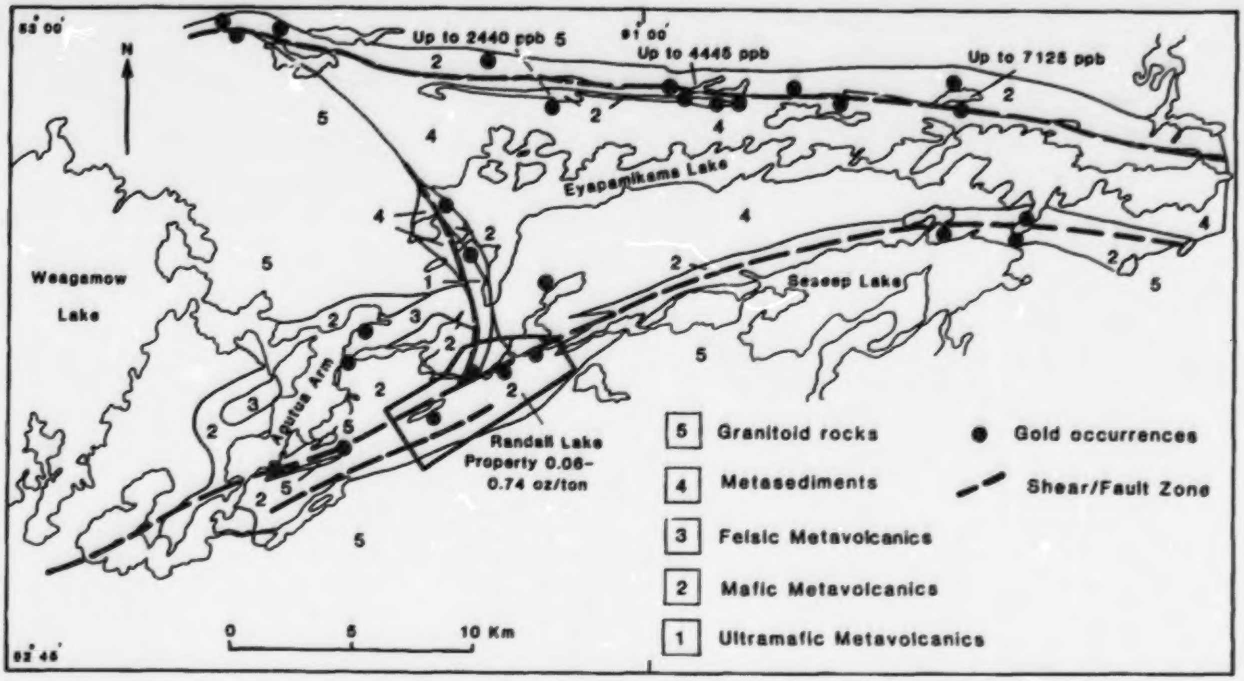

Figure 6.6. *Geology and gold occurrences in the Eyapamikama Lake area of the North Caribou Lake Greenstone Belt. Many gold occurrences in this area are related to major shear zones.*

zone east of the fault, indicating right-handed movement. Stott and Janes (1985) and Thurston *et al.* (1979) mapped this structure in the Wunnummin Lake and Big Trout Lake areas, respectively, and reported that it shows subhorizontal right-handed movement.

The aeromagnetic interpretation of the SWFZ is reinforced by schistosity trends that are in close agreement with the magnetic trends. These linear magnetic trends converge from the west-southwest into the shear zone, and become parallel to the shear zone domain. This constricted spacing of magnetic anomalies is believed to reflect the schistosity, which is consistent with an increase in strain toward the sheared domain (Figure 6.3).

Between Big Trout Lake and Stull Lake, the SWFZ forms a broad deformation zone. In the Stull Lake Greenstone Belt, this zone is characterized by moderate to strong schistosity, altered (silicified ± carbonatized) lithologies, sulphidized quartz ± carbonate veins and gossan zones, and numerous parallel to subparallel mappable shear zones (Thurston *et al.* 1987; Satterly 1938).

ECONOMIC GEOLOGY

Gold mineralization occurs along the SWFZ in the Stull, Swan, and Mameigwess lakes areas. At Stull Lake, gold assay results from sulphidized quartz ± carbonate veins, gossan zones, silicified rocks, and individual shear zones range from 100 ppb to 4 ounces gold per ton (unpublished assay data *from*: Thurston *et al.* 1987; Bennett and Riley 1969; Satterly 1938; Assessment Files Research Office, Ministry of Northern Development and Mines, Toronto).

In the Swan Lake Greenstone Belt, between Stables and Meston lakes, minor gold mineralization is also reported (Meen 1938) from shear zones, and shear-controlled quartz veins interpreted to be associated with the main deformation zone (SWFZ).

In the Mameigwess Lake area, two shear-controlled quartz ± carbonate veins, hosted by the mafic metavolcanics of the Rowlandson belt, occur adjacent to subsidiary zones of the SWFZ. Assay results of up to 0.79 ounce gold per ton were obtained from chip samples of these veins (Prest 1940).

Though no gold occurrences are reported from the Mameigwess Lake greenstone belt, the SWFZ cuts the belt. Aeromagnetic and geological data suggest complex folding of supracrustal sequences southwest of the deformation zone (SWFZ). These folds, which may have no direct relation to the SWFZ, can be followed discontinuously on the aeromagnetic map (ODM–GSC 1963g, Map 7014G) using iron formation marker units. Gold mineralization is associated with similar structures (folds, axial planar cleavage, etc.) at Opapimiskan and Sage lakes, and similar associations may exist in the

Mameigwess Lake greenstone belt. The SWFZ, and the area to the southwest, warrant prospecting for possible gold mineralization.

SOUTH KENYON AND NORTH KENYON FAULT ZONES

Other important magnetic features in the northernmost part of the Superior Province are two subparallel west–northwest–trending long linear anomalies of low to moderate intensity. These anomalies have been interpreted to form the boundaries of the Kenyon Structural Zone. The linear anomalies are two faults termed the "North Kenyon Fault Zone" (NKFZ) and the "South Kenyon Fault Zone" (SKFZ) (Figure 6.2).

The SKFZ is traceable east–southeastwards from the Ontario–Manitoba border for approximately 480 km (Figure 6.2). It branches just northwest of the "C" shaped portion of the Kasabonika Greenstone Belt into two subzones. These subzones further branch into subsidiary zones. One branch passes southeastward along the north flank of the Kasabonika belt, and transects the belt east of Croal Lake. The second subzone, which transects the greenstone belts between the Asheweig and Ekwan rivers, continues east–southeastward, eventually disappearing under the Paleozoic cover.

The western portion of the NKFZ transects the Thorne River–Sachigo River Greenstone Belt. It is identified by deflections of schistosity and the presence of minor shear zones, which are generally subparallel to the major structure. A clockwise rotation of magnetic trend lines in one of these belts probably resulted from rotation along a southeast–trending subsidiary fault, suggesting right–handed transcurrent movement along the fault. During the 1988 field season, the presence of the NKFZ was confirmed by locating an approximately 1 km wide protomylonite to mylonite zone within granodiorite at Yelling Lake, near the Ontario–Manitoba border. The rock matrix is extensively altered to chlorite and epidote. Feldspar augen are intensely saussuritized. Some of the feldspar is angular and the quartz is typically in the form of flat ribbons. Asymmetric quartz aggregates with subhorizontal long axes in the granodiorite suggest right–handed strike–slip movement. Approximately 25 percent of the NKFZ is underlain, to the southeast, by Phanerozoic cover.

ECONOMIC GEOLOGY

Although no known gold mineralization occurs along the NKFZ or its subsidiaries, a few small shear zones and quartz veins containing pyrite and chalcopyrite have been reported (Bennett and Riley 1969; Meen 1938) adjacent to the zone, in the Thorne River–Sachigo River belt.

South of the SKFZ, the Ellard Lake Greenstone Belt hosts a few shear zones. These structures may be splays off the SKFZ. Meen (1938) reported shearing, adjacent to the greenstone–granite contact, and abundant quartz–veining throughout the eastern part of the belt. Two subparallel gold–bearing quartz veins parallel the belt's margin and the SKFZ. These veins were mined by the Sachigo Exploration Company, and produced 52 560 ounces of gold and 6126 ounces of silver from 46 457 tons of ore (Bennett and Riley 1969).

WINISK RIVER FAULT

The northwest–trending Winisk River Fault (WRF) is found in the northeasternmost portion of the study area (Figure 6.2). It is characterized by a distinct long linear magnetic signature of low to high intensity. The broad right–handed deflection of the eastward magnetic trend lines is a characteristic signature of a right–handed transcurrent ductile fault zone. The fault zone obliquely crosscuts the east– to southeast–trending Archean structures (Figures 6.2 and 6.3). The most striking feature northeast of the fault (Latitude 53°40′ to 54°15′) is the unique pattern of small oval closely spaced magnetic highs and lows, described as "birds–eye maple" pattern by Bell (1971), which characterize a unique porphyritic pyroxene–bearing granitic rock (Riley 1979). The overall magnetic relief northeast of the fault is higher (up to 1700 gammas) than in the area southwest of the fault. To the southwest, linear and broad diffuse anomalies of generally lower magnetic relief (300 gammas) correspond to supracrustal and granitic rocks, respectively. A few local magnetic anomalies (up to 1800 gammas) in the area represent iron formation intercalated with the metavolcanics and metasediments. The WRF is mainly covered by Phanerozoic sediments (Figure 6.2).

Aeromagnetic data, in conjunction with available geological information, suggest that the WRF truncates the Pikwitonei Subprovince to the northwest, and forms the boundary between the predominantly plutonic Archean Winisk Subprovince to the northeast, and the volcano–plutonic Sachigo Subprovince southwest of the fault (Osmani, in preparation; Card and Ciesielski 1986). Aeromagnetic patterns further indicate that the northwestern end of the fault connects with the east–trending Churchill–Superior Provincial boundary, and that the southeastern end appears to be truncated by the north–northeast–trending Kapuskasing Zone, west of James Bay (Ontario) (Osmani, in preparation).

ECONOMIC GEOLOGY

During the 1960s and early 1970s, geophysical surveys and diamond drilling programs were carried out in the vicinity of WRF (Assessment Files Research Office, Ministry of Northern Development and Mines, Toronto). No economic mineralization was found.

NORTHEAST-TRENDING FAULTS

A few regional-scale northeast-trending faults occur in the study area. These faults have weak aeromagnetic expressions. In some areas, these structures have been traced aeromagnetically, in conjunction with geological and topographical evidence. Examples identified in the eastern part of the study area include a northeast-trending fault approximately 122 km long, extending southwestward from the Ekwan River Greenstone Belt to just north of the Rowlandson Lake belt. This fault is characterized by a long weak magnetic lineament which, in part, coincides with topographic features (lakes, rivers). The fault appears to offset, by left-lateral movement, the Ekwan River metavolcanic belt (Thurston *et al.* 1979) to the north, and granitic gneisses to the south. Based on the distribution of the shear zone-related gold occurrences in the area, these northeast-trending structures are unlikely sites for gold mineralization. They might be of local significance if they crosscut northwest- or east-trending shear zones.

RECOMMENDATIONS

In view of the apparent genetic association of the Golden Patricia gold deposit in the Meen-Dempster Lakes belt with the Bear Head Fault Zone, prospectors should be encouraged to consider the many fault/shear zones that trend southeast and closely follow the granite-greenstone contacts. These strike-slip faults probably developed local splays or horsetail shear zones that transmitted the fault movement into the adjacent greenstone belts. They may have preferentially followed a lithological contact with such units as sheetlike felsic porphyry or banded iron formation. These units could localize the initial fault rupture and provide competent surfaces along which hydrothermal fluid transfer and continued shearing might focus. An example of such a setting may be found along the northeastern margin of the Keezhik Lake belt, where structural and stratigraphic conditions are suspected to be similar to those of the Golden Patricia Mine in the Meen-Dempster Lakes Greenstone Belt.

The narrow shear zone that hosts the Golden Patricia Deposit demonstrates that these targets may be elusive, and require careful mapping for their discovery. Nevertheless, prospectors should take note of the compelling abundance of long continuous fault/shear zones in the Sachigo Subprovince, and the example of the Golden Patricia Mine on a shear zone that apparently splayed off the Bear Head Fault Zone.

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7. Project Number 88–23. Preliminary Study of the Geochemistry of Alteration in Volcanic Rocks Hosting the Zahavy Mine, Favourable Lake Belt, Sachigo Subprovince

G.R. Edwards[1] **and L.D. Ayres**[2]

[1]Department of Geological Sciences, University of Saskatchewan, Saskatoon, Saskatchewan.

[2]Department of Earth Sciences, University of Manitoba, Winnipeg, Manitoba.

INTRODUCTION

The Zahavy Mine (formerly the Berens River Mine) is about 200 km north of Red Lake in the eastern part of the Favourable Lake supracrustal belt, Sachigo Subprovince, Ontario. The location of the area is shown in Figure 7.1 and can be accessed by a gravel air strip at the mine site. The mine produced 157 341 ounces of gold, 5 676 486 ounces of silver, 6 105 872 pounds of lead, and 1 797 091 pounds of zinc, with an average grade over the life of the mine of 0.29 ounce per ton gold and 11.9 ounces per ton silver.

Detailed mapping of the host rocks in the vicinity of the mine by L.D. Ayres (1969) and by P.S. Buck (1978), an M.Sc. student of L.D. Ayres, provides the geological base for the present work. Additional M.Sc. Thesis work on the precious metal veins at the mine was done by G.W. Adams (1976). The previous stratigraphic work done in the mine area concentrated on the physical description of the host rocks and their mode of deposition with a preliminary examination of their chemistry (Ayres 1969, 1977; Buck 1978).

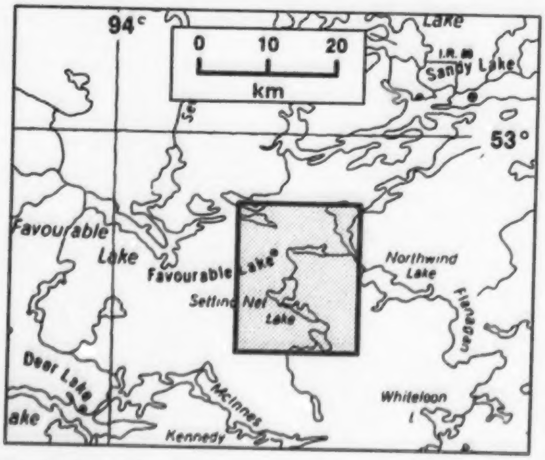

Figure 7.1. *Location map for the Favourable Lake Belt of the Sachigo Subprovince.*

The objective of this project is to characterize the geochemistry of caldera-related volcanic rocks associated with mineralization in the Favourable Lake greenstone belt.

GENERAL GEOLOGY

Five metamorphosed volcanic cycles have been recognized by Ayres (1977) in the eastern part of the Favourable Lake supracrustal belt. The mine is hosted in the second cycle, in a stratigraphically coherent sequence of steeply-dipping intermediate to felsic pyroclastic rocks and flows, informally termed formation H by Buck (1978) (*see* Figure 7.2). This formation is interpreted by Buck (1978) to be of subaqueous to subaerial vent facies occupying a paleo–caldera structure or paleo–volcanic graben. According to Buck (1978) formation H differs texturally, mineralogically, and chemically from other metavolcanic rocks in the area because it has a) poorer preservation of primary textures, b) greater biotite content, c) local garnet, d) widespread pyrite and pyrrhotite, e) muscovite–rich (buff) alteration zones, and f) greater metasomatic changes in major element compositions, relative to surrounding formations. He also concludes that formation H underwent pervasive synvolcanic metamorphism and metasomatism in the form of hot–spring and fumarolic activity, prior to the regional greenschist metamorphic event.

The caldera sequence of formation H is host to vein silver–lead mineralization at the Berens River Mine which had a production history from 1939 to 1948. The belt has since had an exploration history involving re–examination of the mineralization at the Berens River Mine by many companies, the most recent being Zahavy Mines Limited in 1987 (Lavigne and Atkinson 1988). Although production from the mine in the early years was exclusively from zone 1, present exploration has focused on other zones in addition to zone 1. In 1982, 601 500 tons grading 0.19 ounce per ton gold and 4.4 ounce per ton silver were delineated in zone 3. Mineralization in all zones appears to be related to silicification, with quartz–actinolite veins hosting pyrite–pyrrhotite, galena, sphalerite, tetrahedrite, chalcopy-

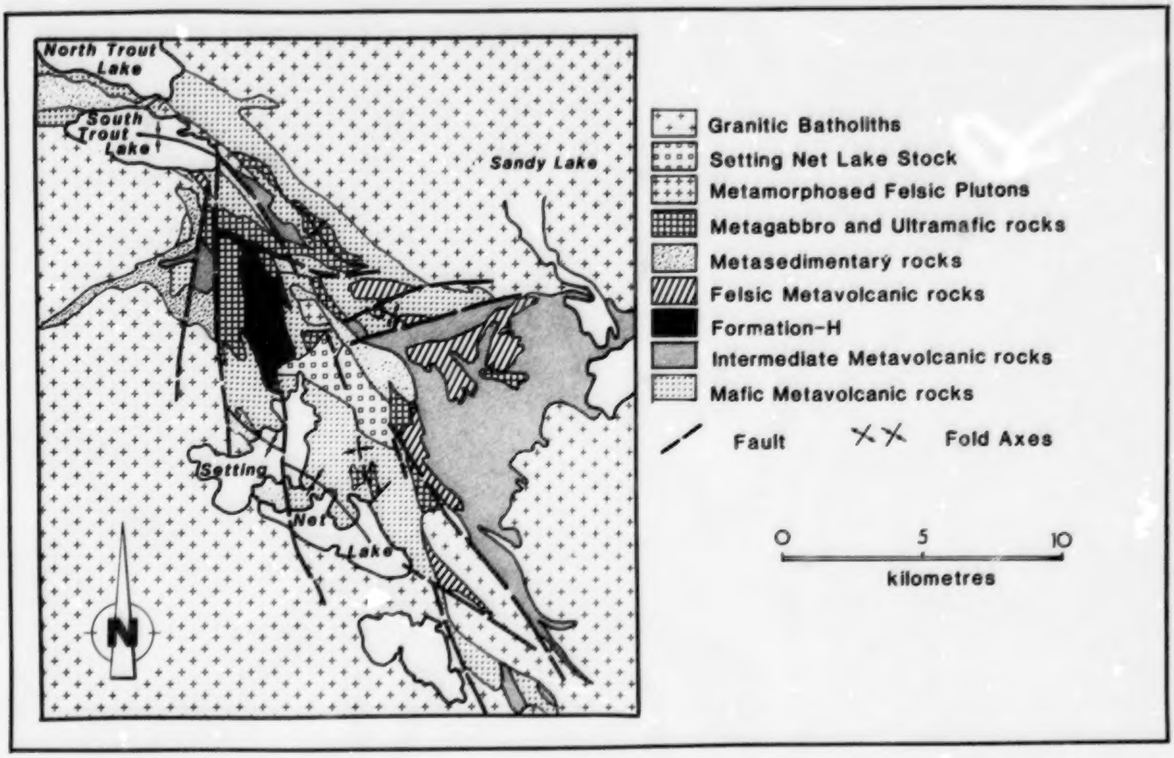
North Trout Lake
South Trout Lake
Sandy Lake
Setting Net Lake
N
Granitic Batholiths
Setting Net Lake Stock
Metamorphosed Felsic Plutons
Metagabbro and Ultramafic rocks
Metasedimentary rocks
Felsic Metavolcanic rocks
Formation-H
Intermediate Metavolcanic rocks
Mafic Metavolcanic rocks
Fault
Fold Axes
0
5
10
kilometres

Figure 7.2. *Generalized geological map and location of the eastern part of the Favourable Lake metavolcanic-metasedimentary belt (Ayres 1977).*

rite, gold, silver (native dyscrasite and ruby silver), and calcite.

PRESENT STUDY

Within the well established framework provided by the earlier stratigraphic studies, the present work seeks to detail the chemical composition of the host and mine rocks and to deduce from their present chemistry, a) their primary composition and primary magmatic fractionation trends, b) the nature and magnitude of their chemical change, both distal from and proximal to the ore zone, c) the nature of the ore-bearing fluids, d) the age of deposition of the ore, and e) by comparison with other volcanic rocks of similar composition, their magmato-tectonic environment of deposition. This study also seeks to test Buck's hypothesis that the "buff" alteration zones have a hot spring or fumarolic origin.

As a start to accomplishing these aims, 44 samples of the host intermediate to felsic volcanics were sampled this summer. Samples were collected predominantly from flows in as broad an area as possible in formation H. A small rock drill was used to take samples of zoned fragments in some pyroclastic units within the buff alteration near the mine. In addition, two samples for U/Pb zircon geochronology were taken; one from granophyric gabbro and one from pegmatitic gabbro intruding sediments lying unconformably upon formation H.

ACKNOWLEDGMENTS

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8. Project Number 88–23. Occurrence of Komatiites in the Favourable Lake Greenstone Belt, Northwestern Ontario

L.D. Ayres

Department of Geological Sciences, University of Manitoba, Winnipeg, Manitoba.

INTRODUCTION

Komatiites have been identified recently in a number of Archean greenstone belts in northwestern Ontario (e.g. Thurston *et al.* 1987). They are particularly well developed in metavolcanic sequences ranging in age from 2980 to 3023 Ma, where many of the komatiites are spatially associated with quartz arenite and limestone units (Thurston *et al.* 1987; Wood *et al.* 1986). This lithologic association appears to characterize ancient platformal sequences that were subsequently overlain by more diverse, deeper water, metavolcanic sequences, many of which range in age from 2700 to 2750 Ma (Wood *et al.* 1986). Recognition of komatiites and associated lithologies thus has potential geotectonic implications.

In the eastern part of the Favourable Lake Greenstone Belt, about 190 km north of Red Lake, numerous concordant serpentinized and locally talcose ultramafic units, most of which do not have associated metagabbroic phases were mapped by the author between 1965 and 1972 (Unit 8 of Ayres 1970, 1972; Unit 7 of Ayres 1974). The location of the area is shown in Figure 8.1. The mapping was done before komatiites were widely recognized, and the ultramafic units were considered to be unusual intrusions. This interpretation is now believed to be incorrect. Cursory examination of one of the ultramafic units in 1974 revealed the presence of spinifex texture (P.S. Buck, personal communication, 1974, currently with the OGS) indicative of komatiites. Subsequent U–Pb zircon geochronologic work has further shown that the spinifex-bearing unit is near other metavolcanic units that have been dated at 2925 Ma (Corfu and Ayres 1987). This spatial association of spinifex-bearing and old metavolcanic rocks prompted a brief reexamination of selected ultramafic units in 1988. As a result of this field work, most previously mapped, concordant ultramafic units that lack associated gabbroic phases, are now considered to be komatiites; both flows and bedded fragmental rocks have been identified.

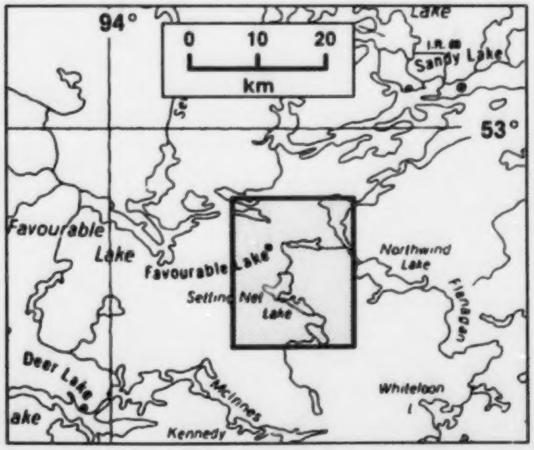

Figure 8.1. *Location map of study area.*

STRATIGRAPHY OF THE GREENSTONE BELT

In the eastern part of the greenstone belt, which has a width of about 13 km, five metavolcanic–metasedimentary cycles comprising 15 formations with an aggregate thickness of 7.5 km were identified by Ayres (1977). The stratigraphy was considered to be a tentative, first approximation because three upright isoclinal folds and numerous faults, several of which are concordant with stratigraphy, have severely disrupted the continuity of units; consequently the correlation of several units across the belt was uncertain. Recent U–Pb zircon geochronologic studies have identified 3 volcanic episodes dated at 2725, 2858 to 2870, and 2925 Ma (Figure 8.2; Corfu and Ayres 1987; Corfu and Ayres, in preparation), have necessitated revision of the stratigraphy, and have confirmed the existence of two major thrust faults (Ayres and Corfu, in preparation). In terms of structural superposition, the sequence of cycles, from cycle 1 at the base to Cycle 5 at the top, remains unchanged, but two of the cycle boundaries are now known to be thrust faults and the structural sequence is not the temporal sequence.

The oldest volcanic episode is represented by Cycle 2 as originally defined by Ayres (1977). This cycle is at least 2.3 km thick and forms the central and southwest part of the mapped segment of the greenstone belt (Figure 8.2). It comprises a lower mafic flow sequence that is separated from an upper, laterally restricted, intermediate pyroclastic and flow sequence by a thin sequence of siltstone, sandstone, marble, chert, and ferruginous chert. Part of the upper intermediate metavolcanic sequence, which hosts the gold–silver–galena–sphalerite–quartz veins of the former Berens River Mine, filled a small cal-

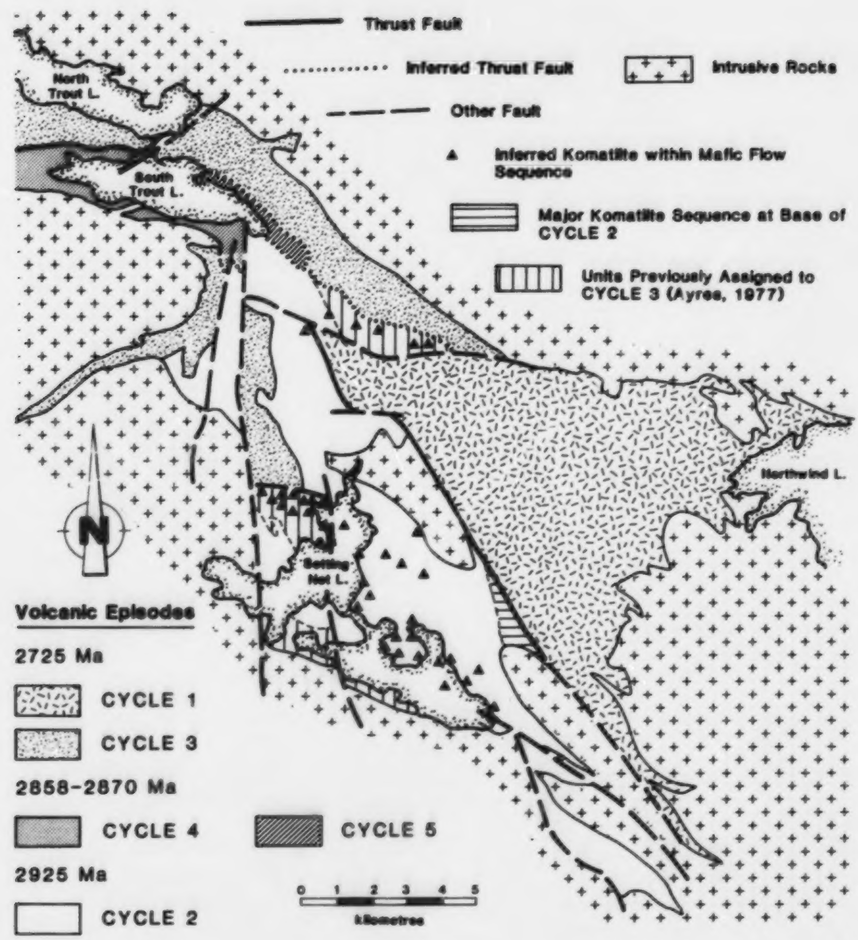
Thrust Fault
Inferred Thrust Fault
Intrusive Rocks
Other Fault
Inferred Komatiite within Mafic Flow Sequence
Major Komatiite Sequence at Base of CYCLE 2
Units Previously Assigned to CYCLE 3 (Ayres, 1977)
North Trout L.
South Trout L.
Northwind L.
Setting Net L.
N
Volcanic Episodes
2725 Ma
CYCLE 1
CYCLE 3
2858–2870 Ma
CYCLE 4
CYCLE 5
2925 Ma
CYCLE 2
0 1 2 3 4 5
kilometres

Figure 8.2. *Stratigraphy of the study area showing the presence of 4 volcanic episodes and associated komatiites.*

dera (Buck 1978). The caldera sequence is capped by a thin conglomerate, sandstone, argillite, chert, and ferruginous chert formation that was apparently deposited in a caldera lake. Overlying the caldera sequence are mafic flows that were originally assigned to Cycle 3 (Ayres 1977). These flows are separated from the type area of Cycle 3 by several faults and by formations assigned to other cycles; their stratigraphic position is now uncertain. In areas where the intermediate metavolcanic and underlying metasedimentary sequences are absent, other mafic flows that were originally assigned to Cycle 3 are probably part of Cycle 2. The reasons for this reassignment are discussed below.

The middle volcanic episode is represented by cycles 4 and 5 as originally defined by Ayres (1977). Both of these cycles, which are contiguous and have a combined thickness of about 1.2 km, are laterally restricted and are confined to the northwest part of the mapped segment of the greenstone belt near South Trout Lake (Figure 8.2). They comprise mafic to felsic flows and pyroclastic rocks with intercalated sandstone, argillite, slate, ferruginous chert, and iron formation.

The youngest volcanic episode comprises Cycles 1 and 3 as defined by Ayres (1977). Cycle 1, which forms the southeast part of the belt (Figure 8.2), was originally considered to be the basal cycle (Ayres 1977). It is largely a sequence of intermediate to felsic flows and pyroclastic rocks, 3 km or more in thickness, capped by thinner, localized iron formation, ferruginous chert, argillite, and mafic flow units. This cycle, which appears to represent a stratavolcano, is now interpreted to be a more proximal facies of part of Cycle 3, from which it is separated by other cycles and by several faults. The 2.5 km thick Cycle 3 on the northwest edge of the greenstone belt (Figure 8.2) comprises a lower mafic flow sequence overlain by a conglomerate–greywacke sequence that was deposited in a progressively deepening basin; the provenance of the metasedimentary sequence includes both the volcano of

Cycle 1 and 2950 Ma granitoid rocks similar to those presently exposed north of the greenstone belt (Corfu *et al.* 1985; Corfu and Ayres in preparation; Gordanier 1982; Hillary and Ayres 1980).

Thrust faults have been identified between Cycle 1, which is part of the youngest volcanic episode, and the structurally overlying Cycle 2, the oldest volcanic episode; and between cycle 3 which is the other part of the youngest volcanic episode, and the structurally overlying Cycle 4, part of the middle volcanic episode (Figure 8.2; Ayres and Corfu in preparation). Both faults were mapped by Ayres (1970, 1972, 1974), but the structural significance of the faults was not known.

KOMATIITES

The ultramafic units that are now defined as komatiites occur either in Cycle 2 or within mafic flows that were previously assigned to Cycle 3. Two areas were briefly examined during the 1988 field season: a thick unit at the base of Cycle 2, and several thin units intercalated with mafic flows that were previously assigned to Cycle 3.

In Cycle 2, the oldest volcanic episode, the examined komatiites form a northwest-trending, wedge-shaped unit up to 640 m thick at the base of the cycle. This komatiite unit is overlain by mafic flows, but the base is a thrust fault which here appears to be slightly discordant; the unit has been traced laterally for 4 km, and it is truncated on the south by granitoid rocks of the Setting Net Lake Batholith (Figure 8.2; Ayres 1972). Where examined, this unit is a sequence of flows. The flows range in thickness from about 1 to 5 m and comprise both pillowed and non-pillowed units; lateral extents of flows are undefined. Pillows were relatively rare and range in thickness from 0.3 to 0.5 m and in length from 0.5 to 1 m. Some of the non-pillowed flows have well developed upper spinifex zones up to 2 m thick underlain by cumulate olivine-rich zones. Flows tops vary from brecciated to unbrecciated and are slightly undulating; the boundary between spinifex and cumulate zones is also undulating but the amplitude of the undulations is greater and is up to 0.5 m. Although no primary minerals were preserved in the few samples examined petrographically, textures are well preserved by pseudomorphs.

Elsewhere in Cycle 2, lenticular, concordant, ultramafic units that are generally less than 20 m thick and 0.5 km long occur locally within sequences of mafic flows (Figure 8.2). One of these units northeast of the former Berens River Mine site was examined by G.R. Edwards (Professor, University of Saskatchewan, Saskatoon, Saskatchewan, personal communication, 1988) who observed flow contacts but no spinifex texture. In the same area, the author has previously observed layered ultramafic units that locally contain cross-stratification; these are now interpreted to be komatiitic tuff, possibly of hyaloclastic origin. Although the other ultramafic units were not examined, they are all interpreted to be komatiites because of the lack of associated metagabbro, and similarity in size and external morphology to units that that were examined in mafic flow sequences previously assigned to Cycle 3.

On the northwest shore of Setting Net Lake, lenticular, concordant, ultramafic units that range in thickness from 20 to 120 m and in length from 0.2 to 1.5 km are intercalated with mafic flows that were previously assigned to Cycle 3 (Figure 2). The ultramafic units comprise 30 to 50% of a 300 m thick interval in the core of a syncline. Several of these ultramafic units were examined and they include both spinifex-textured flows and bedded units that are probably hyaloclastitic tuff. One of the bedded units is 60 m thick and contains beds ranging in thickness from 0.2 to 30 cm although most beds are 0.5 to 1 cm thick. Low angle crossbedding was locally observed in this unit. Beds are defined by textural variations, and, although textures are poorly preserved, particles generally appear to be less than 2 mm in size.

DISCUSSION AND CONCLUSIONS

The mafic-ultramafic flow sequence immediately northwest of Setting Net Lake was originally assigned to Cycle 3 because underlying flows contain intercalated sandstone units that were correlated with the sandstone at the top of Cycle 2 (Ayres 1970, 1977). However, this stratigraphic assignment was uncertain because intermediate metavolcanic rocks, which elsewhere define the upper part of Cycle 2, are absent here, and the mafic sequence is separated from the type area of Cycle 2 by a fault and by Setting Net Lake. This stratigraphic assignment is now believed to be erroneous.

Elsewhere in the mapped part of the greenstone belt, concordant ultramafic units that are interpreted to be komatiites are almost entirely restricted to the mafic parts of Cycle 2. These Cycle 2 mafic-ultramafic sequences are very similar to the sequence that was previously assigned to Cycle 3. Consequently, on the basis of the occurrence of abundant intercalated komatiites, this sequence is reassigned to Cycle 2.

With this stratigraphic revision, which will be documented elsewhere (Ayres and Corfu, in preparation; Corfu and Ayres, in preparation), komatiites in the mapped part of the Favourable Lake Greenstone Belt are thus largely within Cycle 2, the oldest volcanic episode (Figure 8.2). The komatiites form both a thick sequence, 640 m or more, at the apparent base of the cycle, and thinner intercalated units within the overlying 2.5 km thick mafic-ultramafic sequence. The apparent restriction of komatiites to the 2925 Ma volcanic sequence is comparable to that found, or inferred, in many other greenstone belts in northwestern Ontario (Thurston *et al.* 1987).

ACKNOWLEDGMENTS

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9. Project Number 88–34. Geology of the Berens Subprovince: Nungesser Lake Area, District of Kenora

Denver Stone

Geologist, Precambrian Geology Section, Ontario Geological Survey, Toronto.

INTRODUCTION

The Berens Subprovince in northwestern Ontario comprises an extensive, but largely unmapped plutonic terrane north of the Red Lake and Birch–Uchi metavolcanic belts of the Uchi Subprovince (Ayres *et al.* 1971). The relationship of the Berens to the Uchi is uncertain and no clear subprovince boundary has been observed separating the two subprovinces.

The trend of lithological units and structures in most of the Superior Province is largely east–west. The Berens Subprovince, however, has a north–south fabric defined by small supracrustal belts (Ayres *et al.* 1973) and north–trending aeromagnetic elements which cannot be clearly explained by the existing reconnaissance mapping (Donaldson 1969).

The supracrustal belts of the Berens Subprovince in general are smaller and higher in metamorphic rank than the supracrustal sequences in the adjacent subprovinces, yet they contain complex stratigraphy (Cortis *et al.*, this volume). Large–scale sigmoidal west– to northwest–trending shear zones with associated gold occurrences (Osmani and Stott, this volume) cut across extensive sections of the Uchi and Sachigo subprovinces. These shear zones have not been observed in the Ontario segment of the Berens Subprovince.

The mineral potential of the Berens Subprovince is poorly known: sulphide occurrences appear to be characterized by higher concentrations of lead than elsewhere in the Superior Province (c.f. Sangster 1972; Assessment Files, Assessment Files Research Office, Ontario Geological Survey, Toronto). Uranium occurs widely (Bond and Breaks 1978).

The present reconnaissance investigations are the basis for future mapping of the general geology, structure, and mineralization environments of the Berens Subprovince. The 1988 field work of approximately one–month duration characterizes the main lithological elements and the structural style of the Nungesser Lake area north of Red Lake (Figures 9.1 and 9.2). This area, of approximately 2000 km^2 in size, is located approximately 50 km north of Red Lake and includes map sheets 52 N/5

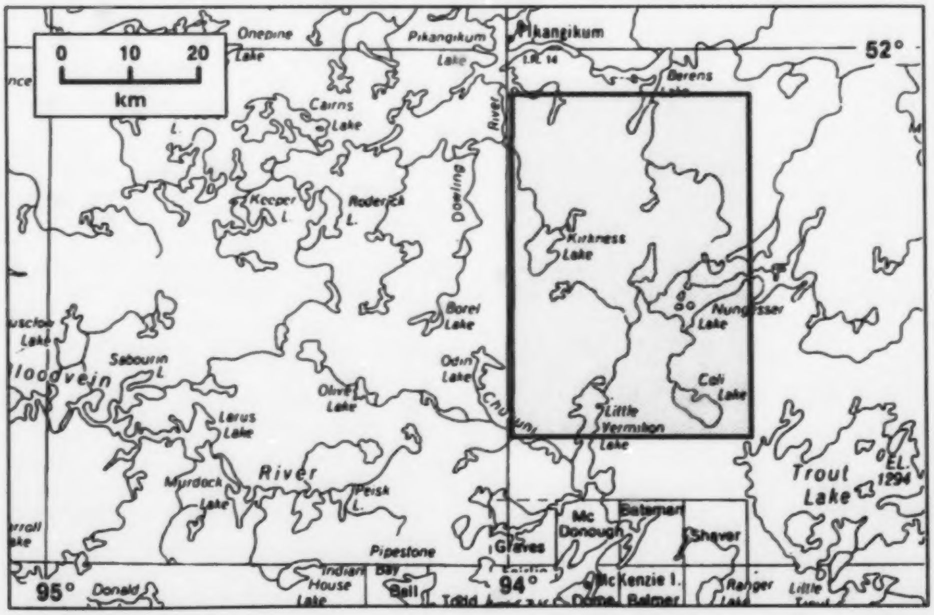
0
10
20
km
Onepine Lake
Pikangikum Lake
Pikangikum
I.R. 14
Berens
52°
Cairns Lake
L.
River
Keeper L.
Roderick L.
Dowling
Kirkness Lake
Borel Lake
Nungesser Lake
Sabourin L.
Bloodvein
Odin Lake
Olive Lake
Chukuni
Cali Lake
Little Vermilion Lake
Larus Lake
River
Murdock Lake
Peisk L.
Trout Lake
EL. 1294
Mc Donough
Bateman
Shaver
Graves
Pipestone Bay
Indian House Lake
Ball
94°
McKenzie I.
Balmer
Ranger Lake
Little
95°
Donald

Figure 9.1. *Location map for the Nungesser Lake area.*

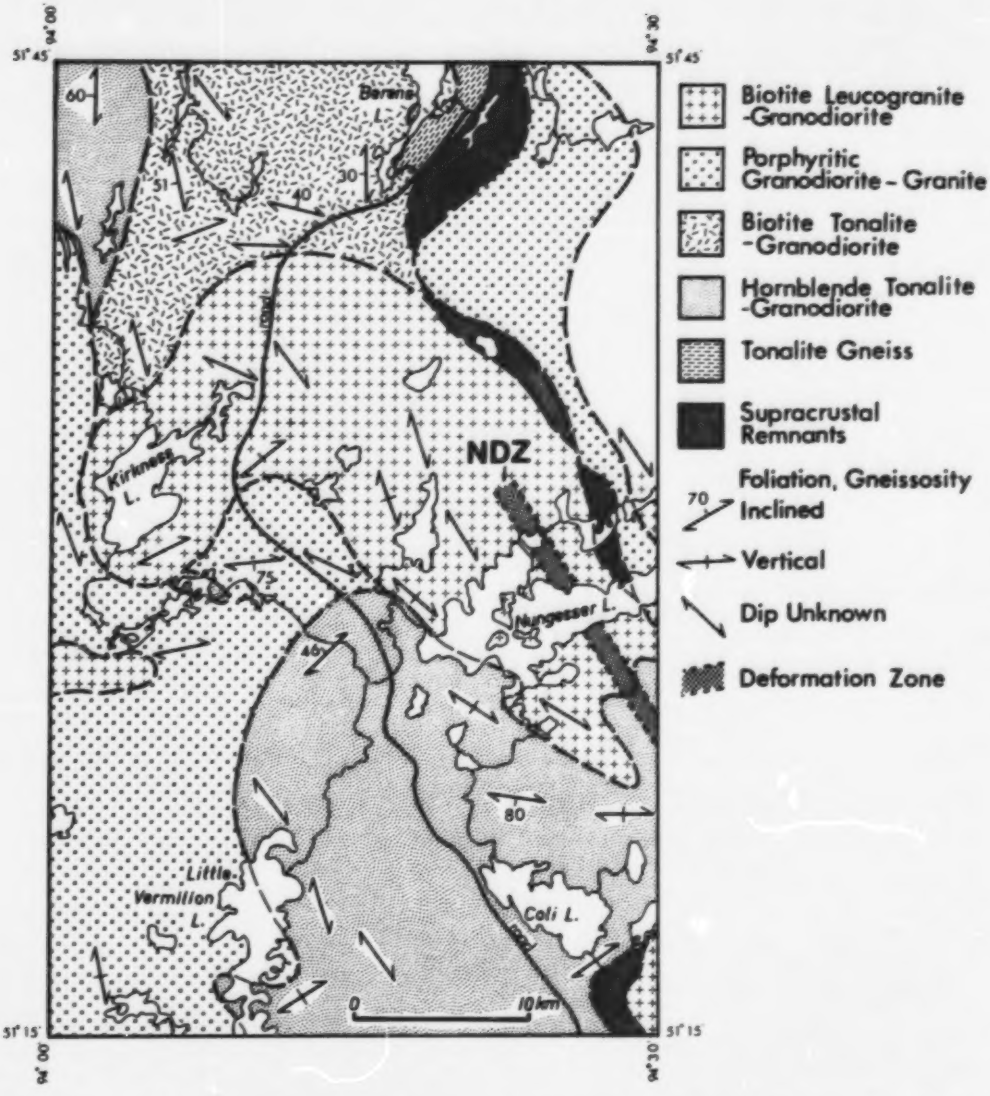
94°00'
51°45'
93°30'
51°45'
51°15'
94°00'
93°30'
51°15'
Berens L.
Kirkness L.
Nungesser L.
Little Vermilion L.
Coli L.
NDZ
60
51
30
40
75
46
80
0
10km
Biotite Leucogranite -Granodiorite
Porphyritic Granodiorite - Granite
Biotite Tonalite -Granodiorite
Hornblende Tonalite -Granodiorite
Tonalite Gneiss
Supracrustal Remnants
Foliation, Gneissosity
70
Inclined
Vertical
Dip Unknown
Deformation Zone

Figure 9.2. *Geology of the Nungesser–Berens Lake area, compiled in part from Horwood (1940) and Donaldson (1969). NDZ is Nungesser Deformation Zone.*

and 52 N/12 of the National Topographic System. Access to the area is by means of the Nungesser Lake Road and float–equipped plane.

PREVIOUS WORK AND MINERAL EXPLORATION

Reconnaissance mapping (Donaldson 1969) showed that the area is underlain by a variety of massive and foliated plutonic rocks and paragneiss. The boundaries and internal fabric of these lithological elements define an overall northerly structural trend.

The small curved belt of supracrustal rocks, which extends into the southeastern corner of the area shown in Figure 9.2, was the subject of detailed mapping by Horwood (1940). Between 1977 and 1980, Dome Exploration Limited carried out an airborne magnetic survey, ground magnetic and electrical surveys, and diamond drilling south of Nugesser Lake (Assessment Files, Resident Geologist's Office, Ministry of Northern Development and Mines, Red Lake). Drill targets were mainly geophysical anomalies with minor pyrite and pyrrhotite in supracrustal rocks and the Nungesser Deformation Zone.

LITHOLOGY

Six lithological units are distinguished on the basis of primary features, texture, and mineralogy. These include metavolcanic and metasedimentary remnants, tonalite gneiss that may be of mixed supracrustal and plutonic origin, and a suite of sodic to potassic intrusive rocks. Igneous rocks are classified according to Streckeisen (1976).

SUPRACRUSTAL REMNANTS

Metamorphosed supracrustal rocks of both volcanic and sedimentary parentage occur within a thin, curved discontinuous belt that extends north through the area (Figure 9.2). Most remnants consist of amphibole–bearing gneisses and biotite migmatites.

The predominant lithological component is a grey, moderately leucocratic (15 to 30 percent mafic minerals) amphibolitic gneiss. This rock is transitional to black hornblende gneiss within which attenuated pillows are recognized southeast of Coli Lake. Volcanic clasts of mainly intermediate composition are noted within amphibolitic gneisses east of Berens Lake. The clasts show aspect ratios on the order of 100 to 1 and indicate high levels of strain in the supracrustal belt.

Metasedimentary migmatites occur east of Berens Lake and north of Nungesser Lake. The migmatites show a lit–par–lit arrangement of fine-grained biotite melanosome and coarse, white granite leucosome. Metasedimentary migmatites north of Nungesser Lake show biotite–garnet and possibly cordierite–bearing assemblages.

Dikes and irregular masses comprising several phases of felsic plutonic rocks transect the supracrustal belt. Contacts are mainly intrusive.

TONALITIC GNEISSES

Supracrustal remnants at Berens Lake and at two localities east of the map area are in gradational contact with grey tonalitic gneisses. Like the supracrustal rocks, tonalitic gneisses are highly deformed, and occupy thin curved belts.

The grey gneissic rocks are composed of medium–grained plagioclase, quartz, and biotite with lesser potash feldspar and amphibole. A prominent compositional layering is defined mainly by variation in the abundance of mafic minerals (typically from 10 to 40 percent). Amphibole is abundant in mafic layers making mafic varieties of tonalitic gneiss transitional to amphibolitic gneiss. At the felsic end of the spectrum, tonalitic gneisses loose their prominent compositional layering and are transitional to biotite tonalite.

HORNBLENDE TONALITE–GRANODIORITE

Hornblende tonalite–granodiorite is both a widespread and distinctive unit. The large irregular pluton at Coli Lake is in contact with the Red Lake greenstone belt to the south and is of unknown lateral dimensions. Hornblende tonalite–granodiorite also extends beyond the northwestern corner of the area and underlies most of Pikangikum Lake and northern Berens Lake.

The tonalite is coarse grained, foliated grey to white weathering, and contains 15 to 25 percent blocky and prismatic aggregates of hornblende and biotite. Biotite dominates over hornblende in leucocratic and well–foliated varieties. Potash feldspar megacrysts are common, particularily in the Little Vermilion Lake area where hornblende tonalite is transitional to porphyritic granodiorite. Adjacent to the Red Lake belt, the unit is transitional to quartz diorite and contains abundant xenoliths of amphibolite.

Most outcrops contain small (10 cm scale) mafic lenses and are transected by pink leucocratic granodiorite dikes. Pods of coarse–grained hornblendite and amphibolite, up to a kilometre in size, are found at scattered localities.

BIOTITE TONALITE–GRANODIORITE

Biotite tonalite–granodiorite underlies a large region in the north–central part of the map area and occurs as thin conformable units in tonalitic gneisses and supracrustal remnants. Hand specimens show a medium grain size and are leucocratic (5 to 10 percent biotite and accessory amphibole) compared to hornblende tonalite. Several phases of biotite tonalite, some of which are transitional to granodiorite in composition, are recognized on the basis of grain size, texture, and mineralogy. Dikes of potash–enriched varieties are youngest in age and transect hornblende tonalite, tonalite gneiss, and supracrustal remnants.

PORPHYRITIC GRANODIORITE–GRANITE

A coarse grain size and abundant blocky megacrysts of potash feldspar are distinguishing features of this unit. Biotite and accessory amphibole comprise from 10 to 20 percent of the mineral constituents.

Porphyritic granodiorite–granite has intruded adjacent to the belt of supracrustal remnants and occurs extensively in southeastern parts of the map area. Textural changes including decreased grain size and development of a prominent foliation occur adjacent to other units. Depletion of potash feldspar and enrichment of hornblende yields a compositional gradation to hornblende tonalite in the Little Vermilion Lake area.

BIOTITE LEUCOGRANITE–GRANODIORITE

Biotite leucogranite–granodiorite is the youngest major lithological unit and comprises a large oblate intrusion central in the area as well as dikes, which transect all other lithologies. Rocks of this unit display a characteristic pink colour and are made up of subequal volumes of quartz, plagioclase, and potash feldspar with usually less than 10 percent biotite and accessory amphibole. A uniform, medium grain size is noted at Nungesser Lake, but elsewhere the unit is inequigranular with isolated potash–feldspar megacrysts and pegmatitic zones. Mafic schlieren and variably assimilated xenoliths of other units can be found in most outcrops.

MAFIC DIKES

Dikes of fine–grained amphibolite, typically 0.1 to 1.0 m wide, transect biotite tonalite and hornblende tonalite in the northwestern corner of the area. Orientations are variable but mainly subvertical (Table 9.1). These dikes are folded and boudinaged and the filling materials show a prominent foliation. Mafic dikes have not been identified in the biotite leucogranite, possibly indicating that they predate the latest stages of felsic plutonism.

AGE RELATIONS

Relative ages of most major units, particularly the younger varieties, are readily established from cross-cutting relations. The highly deformed and intruded remnants of supracrustal rocks and gneisses are clearly among the oldest units in the area (Table 9.2).

The relative age of biotite tonalite–granodiorite is enigmatic at present. Several phases, some of which post–date supracrustal remnants, are included in this unit, however, other phases that occupy conformable lenses within the gneisses and supracrustal rocks are of undefined relative age.

Hornblende tonalite–granodiorite, which contains abundant gneissic and metavolcanic xenoliths, intrudes supracrustal remnants as well as metavolcanic rocks of the Red Lake Belt where it has a U–Pb zircon age of 2731 Ma (Andrews *et al.* 1986). Although porphyritic granodiorite–granite is compositionally gradational to hornblende tonalite–granodiorite, it contains xenoliths of the latter and probably comprises a distinct plutonic event. Mafic dikes and biotite leucogranite–granodiorite are the youngest intrusive rocks.

TABLE 9.1. ORIENTATIONS OF MAFIC DIKES.

Strike	Dip
111	90
030	90
170	52
070	90
015	28

TABLE 9.2. RELATIVE AGES OF PLUTONIC AND SUPRACRUSTAL ROCKS IN THE NUNGESSER LAKE AREA.

Young	biotite leucogranite-granodiorite mafic dikes
	porphyritic granodiorite-granite biotite
	hornblende tonalite-granodiorite tonalite
Old	supracrustal remnants, tonalite gneiss grano-diorite

Although absolute age determinations have not been made in this area, extensive isotopic studies on similar lithologies elsewhere in the Berens and Uchi subprovinces (e.g. Ermanovics and Wanless 1983) indicate mainly late Archean ages. For example, felsic plutons were emplaced within and adjacent to the Red Lake belt at 2731 to 2700 Ma, however, the Red Lake belt contains metavolcanic sequences that range in age from 2733 to 2992 Ma (Andrews *et al.* 1986). This suggests that supracrustal and gneissic units in the adjacent Berens Subprovince can be possibly as much as several hundred Ma older than the majority of plutonic rocks.

METAMORPHISM

With the exception of biotite leucogranite–granodiorite, all units are foliated and recrystallized and show mineralogy indicating that they have been both deformed and metamorphosed. The assemblage hornblende–plagioclase–quartz±epidote is widespread in amphibolitic gneisses of metavolcanic origin. Metasedimentary remnants have undergone partial melting and assemblages of garnet–biotite and possibly cordierite–biotite are present north of Nungesser Lake. Evidently, much of the area was metamorphosed at amphibolite facies conditions.

Epidote and chlorite are noted locally in fractures, small faults, and the Nungesser Deformation Zone indicating that late brittle deformation of the region may have occurred under greenschist facies conditions.

STRUCTURE

SHAPE OF UNITS AND STRUCTURAL TRENDS

Lithological units show distinctive shapes that partly reflect their age and extent of deformation. Young undeformed intrusions, such as the biotite leucogranite–granodiorite pluton central in the map area, are crudely elliptical in plan view and characterized by convex outward extensions.

Intrusions of intermediate age can retain an overall elliptical shape but contain concave embayments, usually occupied by younger intrusions. The biotite tonalite–granodiorite pluton is an example of this type. Oldest units show evidence of high strain and occupy thin curved belts.

Mineral foliations and gneissosity tend to be more intensely developed in old rocks. Foliation trajectories are mainly subparallel to adjacent boundaries of plutonic bodies and show an overall north to northwesterly trend in the map area and central Berens Subprovince.

FOLDS AND LINEATIONS

Outcrops of tonalite gneiss and supracrustal remnants show mesoscopic folds. East of Berens Lake, these structures are tight to isoclinal and, together with mineral lineations, plunge moderately to the southwest (Table 9.3a). Mafic gneiss layers tend to form parallel folds, some of which have ruptured hinge zones and boudinaged limbs. Intervening felsic layers are thickened at fold closures.

Folds and lineations are not readily identified in felsic plutonic rocks with the exception of hornblende tonalite–granodiorite, which shows a prominent westerly plunging mineral lineation adjacent to supracrustal remnants at Coli Lake.

FAULTS AND FRACTURES

A 1 km wide zone of schistose, mylonitized, and fractured plutonic rocks underlies central Nungesser Lake (Figure 9.2). This deformation zone, the Nungesser Deformation Zone, trends approximately 330° and foliation surfaces within it dip westerly 50° to 80°. A contact of the hornblende tonalite–granodiorite pluton undergoes a sinistral strike separation of 2 km across the zone, however, mineral lineations show highly variable orientation (Table 9.3b) such that the direction of slip and displacement cannot be estimated. Further mapping is required to define both the extent and kinematics of this deformation zone.

All units are transected by subhorizontal and two or more sets of subvertical fractures. Spacing of these fractures is typically 1 to 3 m. In the Nungesser Lake area, subvertical fractures trend mainly 20° to 40° and 160° to 180°.

Fractures with red alteration zones and epidote and chlorite filling materials are common in the hornblende tonalite–granodiorite. Evidently, this and other units were affected by late brittle deformation.

TABLE 9.3A. MINOR FOLD AXES AND MINERAL LINEATIONS IN SUPRACRUSTAL REMNANTS EAST OF BERENS LAKE.

Trend	Plunge
250	22
225	21
230	25
210	48

TABLE 9.3B. MINERAL LINEATIONS IN THE NUNGESSER DEFORMATION ZONE.

Trend	Plunge
285	50
150	13
150	60
220	70
170	32
275	56

SUBPROVINCE BOUNDARY

Subdivisions of the Superior Province (e.g. Card and Ciesielski 1986; Thurston *et al.* 1987) locate the east–northeast trending boundary of the Berens and Uchi subprovinces within southern parts of the present map area. Here, foliation trajectories are subparallel to the postulated boundary, however, there does not appear to be a sharp lithological, structural, or metamorphic discontinuity. For example, the large hornblende tonalite–granodiorite pluton extends from the Red Lake Belt across the boundary. The main lithological basis on which to distinguish the subprovinces at this locality seems to be the presence of considerably less supracrustal rocks in the Berens Subprovince than in the Uchi Subprovince.

SUMMARY

Although dominated by late potassic intrusions, some of which may attain batholithic proportions, the Nungesser Lake area also hosts early sodic plutons, gneisses, and both metavolcanic and metasedimentary remnants. In this respect, the mapped segment of the Berens Subprovince contains the same lithological elements as neighbouring volcano–plutonic and metasedimentary subprovinces, but has a much higher proportion of felsic intrusions.

This segment of the Archean crust records emplacement of at least four distinct phases of igneous rocks. Enrichment in potash feldspar and quartz and depletion in ferromagnesian minerals occurred in successive magmas as compositions changed from tonalite and granodiorite to granite. Early plutons were indented and compressed by late intrusions. Final stages of crustal evolution include diking, faulting on the Nungesser Deformation Zone, and pervasive but mild fracturing.

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10. Project Number 88–23B. Geology of the Eastern Lac Seul Granulite–Amphibolite Facies Transition Zone

F.W. Breaks

Geologist, Precambrian Geology Section, Ontario Geological Survey, Toronto.

INTRODUCTION

High grade gneissic belts form an integral component of the subprovinces of the Superior Province in northwestern Ontario. Recent studies within the English River Subprovince (Beakhouse 1977, Breaks *et al* 1978) have delineated two distinct lithotectonic entities: a clastic, metasedimentary-dominated terrane, and a massive to gneissic, granitoid plutonic terrane. Recently, it has been proposed that these two intra-subprovince terranes be given separate subprovince status (Card and Ciesielski 1985); these have been named the English River Subprovince (ERS) and the Winnipeg River Subprovince (WRS) respectively.

The ERS is dominated by migmatized clastic metasediments which account for approximately 60 percent of its area. It has been interpreted to represent a sedimentary basin at least 800 km in length (Beakhouse 1977; Breaks *et al.* 1978). Interspersed throughout this migmatitic metasedimentary belt, in the form of numerous intra-belt stocks and batholiths, are four distinctive lithological suites (Breaks *et al.* 1978): a) a sodic granitoid suite (25 percent), b) a potassic granitoid suite (6 percent), c) a peraluminous granitoid suite (10 percent), and d) a mafic to ultramafic plutonic suite (2 percent). The four suites very rarely co-exist within the ERS. However, good road and lake access and abundant clean rock exposure in the eastern Lac Seul area make it a

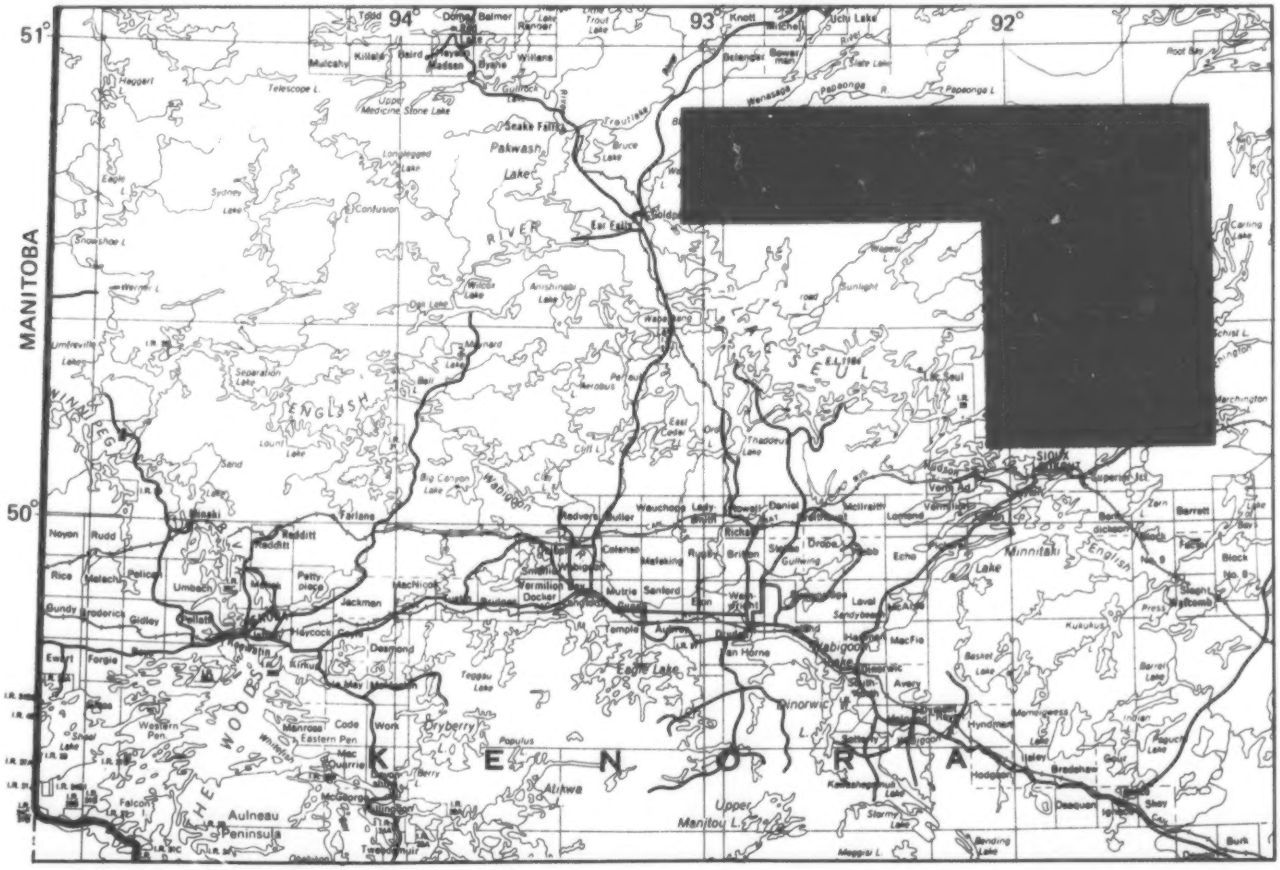


Figure 10.1. *Location map of the Eastern Lac Seul study area, northwestern Ontario. Scale 1: 584 000 or 1 inch to 25 miles.*

good area in which to unravel the relationships among the different suites.

In contrast, the WRS is dominated by stocks and batholiths of felsic to intermediate sodic and potassic plutonic suite rocks (each comprising about 40 percent of the WRS), which intrude earlier, highly deformed, polygenetic, granitoid gneisses (gneissic granitoid suite). The latter compose about 20 percent of the WRS, which comprises a 410 km long terrain that gradually tapers towards the east. Other salient geological features of the WRS include a paucity of remnant metavolcanic rocks and of the peraluminous granitoid suite of the ERS (Breaks *et al.* 1985).

The boundary between the ERS and WRS was lithologically defined by Breaks and Bond (in preparation) as the southern limit of the continuous distribution of migmatized clastic metasediments and anatectically–derived, peraluminous, S–type granitoids in the ERS. Recently, Sanborn–Barrie (this volume) recognized a coincident major zone of faulting along the boundary.

The field relations and petrological and geochronological data utilized to define the granitoid rocks in the two subprovinces are summarized in Breaks *et al.* (1985).

PRESENT SURVEY

Relatively little work has been done in the area subsequent to initial 1:63 360 scale reconnaissance geological mapping between longitude 89°00′ and the Ontario–Manitoba boundary (Breaks *et al.* 1978). This project was initiated to a) better determine emplacement timing of the major granitoid suites, b) conduct a detailed examination of granulite facies metamorphic zones and their transition into amphibolite facies, c) determine the continuity and geological character of metavolcanic belts distributed along the ERS–WRS interface, and d) determine the mineral potential (rare–metals and gold) of peraluminous S–type granitoids.

The project area covers about 2500 km^2 between Bluffy Lake and eastern Lake Seul (Figure 10.1). The northeastern arm of Lac Seul, commencing at Bear Narrows, affords a 40 km transect of the WRS–ERS boundary zone and exposures of the central interior of the ERS. Investigations were concentrated along this transect utilizing previous 1:63 360 scale geological maps as a base (Breaks *et al.* 1979a, 1979b, 1979c, 1979d).

Field work in 1988 included examination of outcrops in both the ERS and WRS, sampling for future geochemical studies, and sampling for U/Pb geochronological determinations. Geochemical and geochronological investigations into these relatively deeper levels of Superior Province crust could provide important constraints in crustal modelling and in the formulation of metallogenetic hypotheses, particularly if models such as that of Kroner (1985), i.e. tectonic juxtaposition of low grade greenstone and high grade gneissic terrains via low angle thrusting, are valid.

GENERAL GEOLOGY OF THE EASTERN LAC SEUL AREA

GNEISSIC GRANITOID SUITE

This suite is rare in the ERS, relative to the WRS in which it occurs as an extensive area of highly deformed tonalitic gneiss known as the Deception Bay Gneissic Complex (DBGC). The DBGC is apparently intruded by the oldest known sodic granitoid suite pluton in the study area, the Sen Bay Pluton (3.3±0.1 Ga, Krogh *et al.* 1976, modified by Hinton and Long 1979).

The gneissic suite comprises a heterogeneous assemblage of complexly intermixed tonalitic units, derived migmatitic leucosomes, arteritic injections of sodic and potassic suite dikes and, typically, rare amounts of supracrustal– and dike–derived amphibolitic remnants.

SODIC GRANITOID SUITE

The sodic granitoid suite constitutes the most abundant plutonic group in the ERS forming stocks and large batholiths completely enveloped by migmatized metasediments (Breaks *et al.* 1978). These rocks are composed of a complex assortment of trondhjemite, tonalite, quartz diorite, and diorite which characteristically become more leucocratic with decreasing relative age (Breaks and Bond, in preparation).

Field relations indicate that the sodic granitoid suite is the oldest plutonic suite in the ERS. As exemplified by the Bluffy Lake Batholith and the Coones Bay Stock, this magmatic suite pre–dates the upper amphibolite to granulite facies regional metamorphism that led to widespread anatexis in the host clastic metasediments. This is revealed by the truncation of a pervasive, strongly recrystallized, foliated to locally gneissic fabric by dikes and small masses of the peraluminous granitoid suite. The latter formed by regional anatexis of clastic metasediments with subsequent mobilization of leucosome into a variety of host lithologies. Sodic suite granitoids have never been observed to post–date the peraluminous or potassic granitoid suites.

In the WRS, one of the most extensive sodic suite batholithic complexes, the Chamberlain Narrows Plutonic Complex (CNPC), is distributed for 43 km along the boundary with the ERS (Breaks and Bond, in preparation). This 2000 km^2 complex is composed of six units which have similar compositions and petrography to the nearby Sen Bay Pluton. Both plutonic complexes are overprinted by dynamic granulite metamorphic assemblages (see metamorphism section).

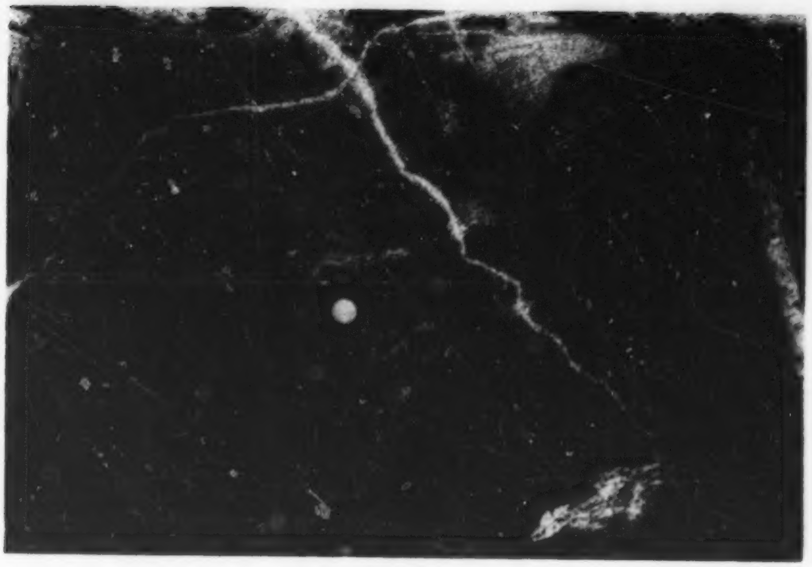


Photo 10.1. *Diopside–orthopyroxene hornblende enclaves in amphibolite on a small island 1.6 km south–southwest of the entrance to Chamberlain Narrows. These inclusions of ultramafic composition may represent tectonically disrupted pillow structures or a former vein system.*

Numerous supracrustal slivers are evident in the CNCP. These include a 65 km long by 0.8 to 6.5 km wide curvilinear metasedimentary migmatite remnant known as the Bear Narrows Belt, and much smaller mafic metavolcanic belts. Such inclusions are largely composed of amphibolitic rocks which locally contain numerous diopside–orthopyroxene–hornblende meta–ultramafic enclaves, some of which are suggestive of tectonically disrupted pillow selvedges or a complex vein system (Photo 10.1). Intercalated, very thinly to thinly bedded, lean banded iron formation (chert+magnetite+orthopyroxene±diopside) and massive to brecciated diopside–rich meta–ultramafic rocks are subordinate. The latter, which can be conformable with BIF units, could represent ultramafic metavolcanic flows.

PERALUMINOUS GRANITOID SUITE

These rocks, previously mapped as homogeneous and inhomogeneous diatexite (Breaks *et al.* 1978), are the petrographically most distinctive felsic plutonic suite in the ERS. From the Ontario–Manitoba boundary eastward to longitude 89°00′, they occupy an area of approximately 3600 km^2 making them the most voluminous S–type granitoids found anywhere in an Archean terrain (Breaks *et al.* 1985).

Evidence from the earlier mapping revealed that at least three generations of peraluminous granitoid rocks exist in the study area: (a) *in situ* leucosomes isoclinally folded by the earliest ductile deformation event, (b) open folded dikes which intrude the above, and (c) post–kinematic planar dikes which cross cut both (a) and (b). This tectono–magmatic sequence suggests a protracted separation of peraluminous leucosome and metasedimentary paleosome components and subsequent segregation into syn–, late–, and post–kinematic batholiths, stocks, and dikes (Breaks and Bond, in preparation).

POTASSIC GRANITOID SIUTE

The youngest granitoid rocks in the ERS and WRS are undeformed post–tectonic dikes and normally small masses of coarse–grained to pegmatitic granite, K–feldspar granite, and quartz syenite. Most of this suite, which comprises only six percent of the ERS, is concentrated within the Fletcher Lake Batholith situated 155 km west of the study area. This plutonic complex is composed of K–feldspar megacrystic granite to granodiorite.

Geochronological work on the potassic granitoid suite within the WRS indicates that these rocks evolved between 2560±40 and 2635±65 Ma (Krogh *et al.* 1976; Beakhouse and McNutt 1980), during the later stages of the Kenoran orogenic plutonic cycle.

MAFIC, ULTRAMAFIC, AND ANORTHOSITIC PLUTONIC ROCKS

Amphibolitic to pyroxene–rich mafic to ultramafic tectonic inclusions occur throughout the migmatized metasediments of the ERS in the eastern Lac Seul area. Many of these inclusions plausibly represent dike remnants. Further south, in the Bear Narrows area of the WRS, possibly related orthopyroxene–bearing amphibolite dikes cross–cut amphibolitic mafic metavolcanics and are post–dated by sodic and potassic granitoid dikes related to static granulite metamorphic events (Photo 10.2).

Photo 10.2. *Relative age progression of sodic granitoid charnockitic dikes emplaced into diopside and orthopyroxene amphibolite previously affected by dynamic granulite metamorphism. Dikes with static granulite metamorphic selvedges (1,2, and 3) are all post dated by a curvate dike biotite granite of the post potassic granitoid suite (dike 4). Arrow points to early mafic dike overprinted by granitoid dikes related to the static granulite metamorphic events. Outcrop is located 4.8 km northeast of Bear Narrows.*

In the WRS, numerous ultramafic and amphibolitic tectonic inclusions are interspersed throughout the Deception Bay Gneissic Complex. Rare anorthositic inclusions are apparently confined to the Bindo Lake area and consist of layered anorthositic gabbro and anorthosite (Breaks and Bond, in preparation).

GRANULITE METAMORPHISM IN THE EASTERN LAC SEUL AREA

Granulite zones in the ERS represent the deepest crustal levels currently known in the Superior Province of northwestern Ontario. These granulites were delineated during 1:63 360 scale reconnaissance mapping (Breaks *et al.* 1979a, 1979b, 1979c, 1979d). The eastern Lac Seul area provides a transect across a 40 km by 65 km, ovoid, low pressure granulite zone. The upper amphibolite–granulite facies transition roughly coincides with the subprovince boundary, although small "nodes" of orthopyroxene+diopside assemblages occur in mafic to intermediate bulk compositions in the WRS at distances up to 13 km south of the boundary.

Breaks *et al.* (1978) estimated metamorphic temperatures in excess of 770°C and load pressures of 4 to 6 kbars for granulite zones of the ERS. Recent geothermometry (garnet–biotite) and geobarometry (garnet–orthopyroxene–plagioclase–quartz) in the eastern Lac Seul granulite zone (Perkins and Chipera 1985; Chipera and Perkins 1988) estimated temperatures of 700° to 750°C and pressures of 4.7±1.0 to 5.4±0.8 kbars. These data indicate that the present exposed Archean crust in this part of the ERS was about 20 km thick.

Field evidence indicates two styles of granulite metamorphism in the eastern Lac Seul region: dynamic (syn–kinematic) and static (late– to post–kinematic). The dynamic event is widespread and is characterized by orthopyroxene associated with a tectonic planar and linear fabric in a variety of bulk compositions (mafic, ultramafic, tonalite, metapelite, and banded iron formation). Two deformation events define this fabric: (a) a relatively early period which produced a well defined foliation commonly enclosing rootless, isoclinal, intrafolial folds, and (b) a subtle, synchronous, mineral stretching lineation oriented at 275/30. These structures, which contain orthopyroxene and diopside, are overprinted (rarely) by open folds (interlimb angle 120°) with axes oriented at 243/65 (Photo 10.1).

Static granulite metamorphism is volumetrically minor and is characterized by assemblages containing orthopyroxene, biotite, plagioclase, and Fe–oxides. However, a greater complexity is evident in that at least five distinct pulses manifested during the late– to post–kinematic history of the region. These assemblages are confined to 0.5 to 5 cm wide, metasomatic selvedges genetically related to dike emplacement, which overprint host amphibolites in two structural settings: 1) up to four distinct, post–kinematic ages of planar dikes of the sodic and potassic granitoid suites (Photo 10.2) and 2) late kinematic tension gash and boudin fillings within

Photo 10.3. *Part of a 2.7 m long broadly sigmoidal tension gash infilled with biotite–orthopyroxene quartz diorite which illustrates the two types of granulite metamorphic events. The dynamic granulite assemblage (D) is associated with a foliation which is overprinted by Fe-oxide+plagioclase+orthopyroxene metasomatic selvedges (S) oriented parallel to the dike margins. Note total replacement of hornblende at the point where this selvedge transgresses the dark intrafolial ultramafic enclave (arrow). Outcrop near Bear Narrows.*

amphibolitic and meta-ultramafic rock (Photo 10.3.)

The selvedges are developed in diopside–orthopyroxene–hornblende–plagioclase amphibolite where a strong contrast is evident due to negative weathering features of the selvedge and a brown colouration due to complete replacement of black hornblende.

Photo 10.2 illustrates the two contrasting types of granulite metamorphism. Here, complete replacement of dynamic, diopside–orthopyroxene–hornblende–plagioclase assemblages by later orthopyroxene+biotite+plagioclase is especially evident within an intrafolial ultramafic lens where it is transected by the tonalite/selvedge system.

Dikes of coarse biotite granite to syenite, belonging to the potassic granitoid suite, locally contain orthopyroxene–biotite–plagioclase selvedges where emplaced into amphibolitic rocks. These selvedges and the local occurrence of orthopyroxene (up to 4 by 5 cm) in this granitoid suite indicate that the static granulite metamorphism outlasted emplacement of the sodic granitoid suite.

GEOCHRONOLOGICAL SAMPLING

A lack of exposed cross-cutting relationships among the granitoid suites of the ERS and WRS has hindered determination of their relative ages and correlation among them. Samples for U–Pb age determinations were selected from 11 different intrusions during the current mapping as an initial step in removing these uncertainties.

GNEISSIC GRANITOID SUITE

A sample (locality 45–2–1, Figure 10.2) was taken of highly deformed tonalitic gneiss from the Deception Bay Gneissic Complex, to evaluate the possibility that these rocks are older than the 3.3 Ga Sen Bay pluton (Krogh *et al.* 1976, modified by Hinton and Long 1979).

SODIC GRANITOID SUITE

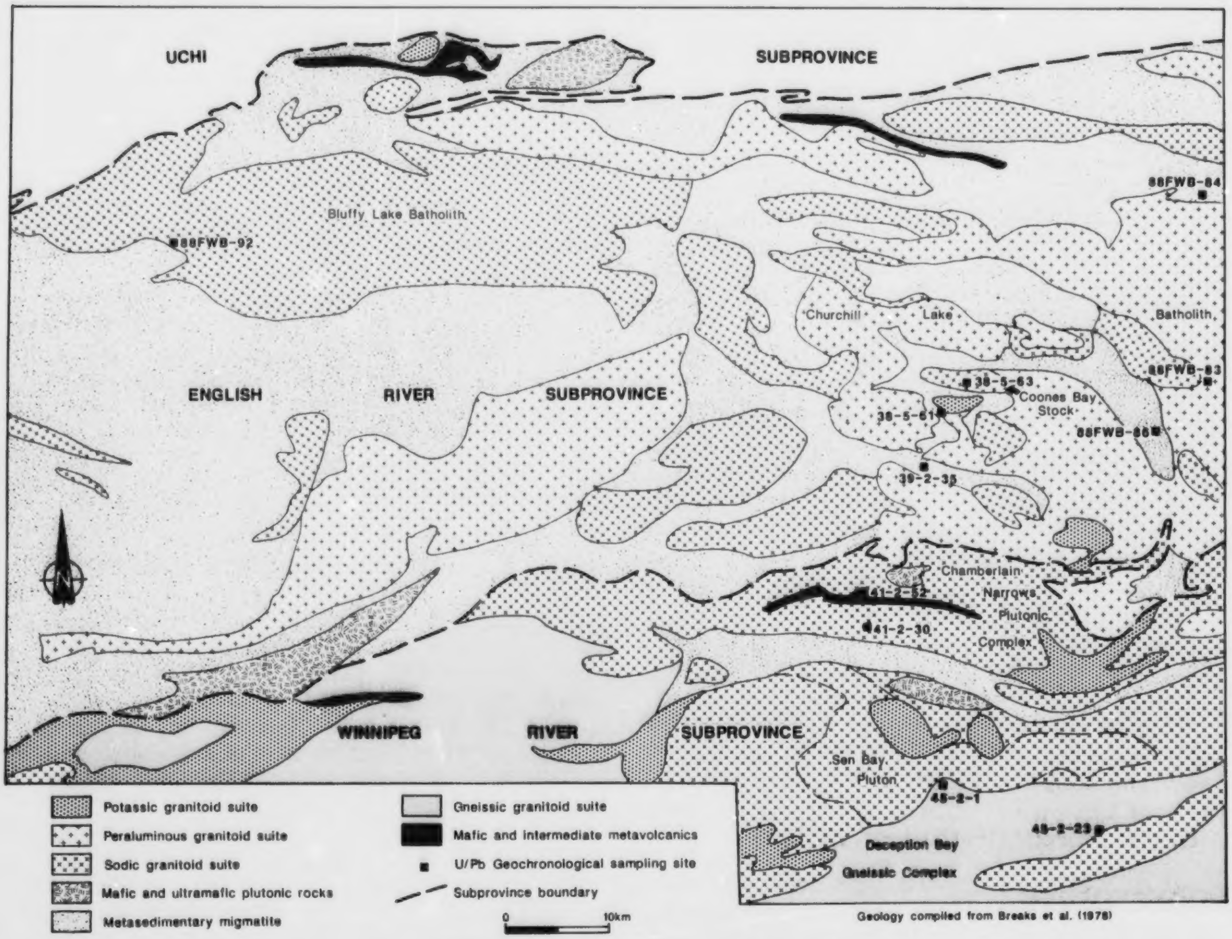
Samples (locations shown on Figure 10.2) were collected from three complexes of this suite. Sample 88FWB–92 is a medium-grained, massive hornblende–biotite granodiorite from the oldest unit of the Bluffy Lake Batholith, the largest sodic suite complex in the ERS. Sample 38–5–63 is from the Coones Bay Stock, a well foliated, grey biotite tonalite in the centre of the eastern Lac Seul granulite zone that is cut by dikes of the potassic and peraluminous granitoid suites. The third sample from the sodic granitoid suite (sample 41–2–30) is a diopside–orthopyroxene–biotite tonalite from the oldest plutonic unit of the Chamberlain Narrows Plutonic Complex (Figure 10.2). This complex, one of the most extensive sodic suite complexes in the southern boundary of the ERS, is petrologically similar to the Sen Bay pluton and may have formed part of the basement to the clastic sediments of the ERS.

PERALUMINOUS GRANITOID SUITE

As described previously (see General Geology of Eastern Lac Seul Area), at least three generations of peraluminous granitoids are known for the study area. To date, only one absolute age (2681±20 Ma; U–Pb zircon, Krogh *et al.* 1976) is available for this suite. Four samples were collected during the current project. Sample 39–2–35 is from leucosomes of *in situ* orthopyroxene–biotite granite to quartz syenite with orthopyroxene–cordierite–biotite melanosome selvedges. This sample should provide the age of initial anatexis in the eastern Lac Seul granulite zone. Sample 38–5–61 is from a cordierite–biotite–garnet granite dike that was apparently generated in the second anatexis. Sample 88FWB–83 is from the Churchill Lake Batholith. This is the largest S–type granite in the ERS; the age of the sample will date the most extensive anatexis event in the ERS, and will provide an upper age limit for the potassic granitoid suite. The last sample (88FWB–84), from a post–kinematic pegmatitic granite dike, will yield the age of the youngest rocks in the peraluminous suite. The dike contains a rudimentary core of blocky K–feldspar, quartz, and tourmaline and may also provide an estimate of the timing of rare–metal pegmatite dike swarms that are distributed along the northern boundary of the ERS in the Root Lake area, some 25 km to the northwest.

POTASSIC GRANITOID SUITE

Three samples of this suite were collected. Sample 41–2–52 is an undeformed biotite granite dike containing local orthopyroxene. It may represent the youngest charnockitization related to the static granulite metamorphism. Sample 88FWB–86 is from an undeformed biotite pegmatite dike that cross-cuts orthopyroxene–garnet–biotite clastic metasediments. Sample 88FWB–89 (not shown in Figure 10.2) is from a yellow–brown weathered, orthopyroxene–bearing zone in the Fletcher Lake Batholith, which is situated in the Umfreville Lake–Conifer Lake granulite zone (Breaks *et al.* 1978). The


UCHI
SUBPROVINCE
88FWB-84
Bluffy Lake Batholith
88FWB-92
Churchill
Lake
Batholith
88FWB-83
38-5-63
Coones Bay
Stock
38-5-61
88FWB-86
ENGLISH
RIVER
SUBPROVINCE
39-2-35
Chamberlain
Narrows
Plutonic
Complex
41-2-52
41-2-30
WINNIPEG
RIVER
SUBPROVINCE
Sen Bay
Pluton
45-2-1
45-2-23
Deception Bay
Gneissic Complex
Potassic granitoid suite
Peraluminous granitoid suite
Sodic granitoid suite
Mafic and ultramafic plutonic rocks
Metasedimentary migmatite
Gneissic granitoid suite
Mafic and intermediate metavolcanics
U/Pb Geochronological sampling site
Subprovince boundary
0
10km

Geology compiled from Breaks et al. (1978)

Figure 10.2. *General geology of the Eastern Lac Seul area, showing the locations of samples discussed in the text.*

age obtained from this sample will establish the age of the batholith and an upper age limit for charnockitic metamorphism, and will allow comparison with similar processes active in the eastern Lac Seul area.

MAFIC, ULTRAMAFIC, AND ANORTHOSITIC PLUTONIC ROCKS

Sample 45–5–23 was taken from an inclusion of anorthositic gabbro in the Deception Bay Gneissic Complex at Bindo Lake. This sample may yield the age of the early sialic crust of the study area, analogous to recently reported anorthositic rocks (3730± 6 Ma) from the Narryer Gneiss Complex in the Yilgarn Craton of Western Australia (Myers 1988a, 1988b; Kinney *et al.* 1988).

RECOMMENDATIONS FOR MINERAL EXPLORATION

Granulite zones of gneissic belts such as the ERS have been postulated to represent possible primary sources of gold, arsenic, tin, carbon dioxide, and various large ion lithophile metals. These metals are variably concentrated in gold deposits of nearby greenstone–dominated subprovinces (Colvine *et al.* 1988). Dehydration mineral reactions leading to replacement of hornblende by orthopyroxene have episodically developed in granulite zones of the ERS and parts of the WRS. Late to postkinematic elimination of hornblende in metasomatic selvedges bordering orthopyroxene–bearing tonalite to quartz diorite dikes is indicative of incipient charnockitization, which likely developed in response to a carbon dioxide–rich fluid phase (Touret and Dietvorst 1983; Holt and Wightman 1983). Such dike systems could also have performed as conduits, facilitating egress of these volatiles and metals to higher crustal levels. Egress may also have been aided by nearby shear zones (e.g. Lake St. Joseph Fault, Miniss River Fault, ERS–WRS boundary fault). It would thus be useful to examine these fault systems for zones of carbonatization and hematitization as a guide to gold mineralization which may reflect streaming of oxidized, carbon dioxide–rich fluids (Cameron 1988) from the granulite zones.

Rare–metal mineralization in fertile granites, consanguineous pegmatites, and possible exogreisen vein zones genetically linked with the peraluminous granitoid suite should also be considered in the ERS–Uchi interface zone. This area has been poorly explored for such mineralization (lithium, cesium, beryllium, rubidium, tantalum, gallium) even though rare–metal pegmatites (Root Lake Field) are known within this zone (Breaks and Bond, in preparation).

CONCLUSIONS

The absolute timing of magmato–tectonic events in high grade gneissic belts such as the ERS in northwestern Ontario remains poorly understood, despite reasonably well understood geological relationships (Beakhouse 1977; Breaks *et al.* 1978). This study has examined new exposures in the contact zone between the ERS and the WRS that reaffirm earlier relative age relationships among granitoid suites of the two subprovinces. The geochronological framework that will result from sampling completed in 1988 will lead to a better understanding of Archean crustal evolutionary processes and mineralization events characteristic of high grade gneissic belts.

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11. Project Number 88–23B. The Petrunka W–Be Property – An Archean Holmquistite–bearing Greisen System

F.W. Breaks

Geologist, Precambrian Geology Section, Ontario Geological Survey, Toronto.

INTRODUCTION

Archean greisen systems have rarely been documented in the literature, possibly due to the supposition that this alteration style is confined to younger anorogenic plutons (e.g. Proterozoic rapakivi granites of southwestern Finland, Nurmi and Haapala 1986), or to younger orogenic belts (e.g. the Hercynian of western Europe, Hutchinson 1983). Greisen alteration is typically localized in the apical parts of alkalic or peraluminous granitic plutons (autometamorphic greisen), or in satellite vein systems which emanate from their cupola zones (exogreisen). These types were termed autometamorphic greisen and exogreisen, respectively, by Shcherba (1970, p.139). Based upon his work in the rare metal pegmatite fields of west and central Africa, Varlamoff (1972, p.207) indicates that greisenization can affect both internal and exocontact pegmatites, depending upon the emplacement level of the parental granite. Hutchinson (1983, p.133) states that greisenization in granite cupolas which have limited veining into host rocks may develop to mesozonal depths of 8 km. This is slightly deeper than the 3.5 to 7 km indicated for rare metal pegmatites of the intermediate level (Ginsburg *et al.* 1979), which most closely match the pegmatites of the study area (i.e. Mavis Lake Group, Breaks *et al.* 1985).

PRESENT STUDY

This study provides a detailed geological and geochemical evaluation of a possible Archean greisen vein system which is characterized by a unique occurrence of the rare lithium amphibole, holmquistite [$Li_2(Mg,Fe^{2+})_3Al_2Si_2O_{22}$]. This vein system constitutes a new environment of rare metal mineralization in Archean rocks of northwestern Ontario. The study area is located in Zealand Township, approximately 0.7 km south of the Dryden Airport (Figure 11.1). Detailed geological mapping (1:50 scale) and collection of geochemical specimens was carried out during the 1988 field season.

MINERAL EXPLORATION HISTORY

Rare metal mineralization in Zealand Township was initially reported by Satterly (1941, p.55), who remarked on beryl specimens brought to him by J.G. Taylor. The actual mineralized pegmatites were later investigated during the 1960s by R. Pidgeon (R. Pidgeon, Prospector, Wabigoon, personal communication, 1981).

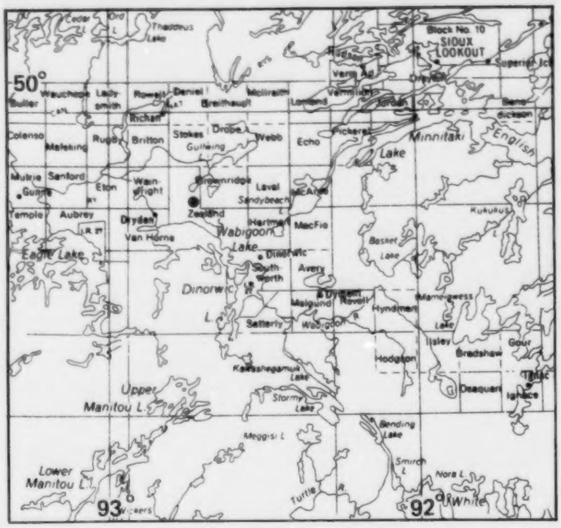
Cedar L
Ord L
Thaddeus Lake
Block No. 10
SIOUX LOOKOUT
Superior Jct
Vermilion
Jordan
50°
Wauchope
Ladysmith
Rowell
Daniel
Breithaupt
Mcllraith
Lomond
Buller
Richan
Colenso
Mafeking
Rugby
Britton
Stokes
Drope
Gullwing
Webb
Echo
Pickerel
Minnitaki
Lake
English
Mutrie
Sanford
Eton
Wainwright
Brownridge
Laval
Sandybeach
McAree
Gunne
Temple
Aubrey
Dryden
Zealand
Hartman
MacFie
Kukukus L
Van Horne
Wabigoon
Lake
Dinorwic
Basket Lake
Eagle Lake
South Worth
Avery
Dinorwic L.
Melgund
Revell
Hyndman
Manitou L
Lake
Satterly
Wabigoon R
Ilsley
Bradshaw
Gour
Hodgson
Kawashegamuk Lake
Upper Manitou L.
Stormy Lake
Osaquan
Ignace
Bending Lake
Meggisi L
Lower Manitou L.
Smirch L
Nora L.
Turtle R.
93°
Vickers
92°
White

Figure 11.1. *Location map for the Petrunka W–Be property, northwestern Ontario. Scale 1:1 584 000 or 1 inch to 25 miles.*

Scheelite was discovered in the study area by D. Petrunka (D. Petrunka, Prospector, Thunder Bay, personal communication, 1985). Initial evaluation of this occurrence was undertaken by Noranda Mines Limited, which reported channel samples containing up to 0.1 percent WO_3 (Blackburn and Hailstone 1983, p.12–13). From 1981 to 1984, a 32–claim block was investigated by Samine Exploration Incorporated, mainly by surface evaluation and a limited amount of diamond drilling (Assessment Files Research Office, Ontario Geological Survey, Toronto).

PREVIOUS GEOLOGICAL INVESTIGATIONS

Satterly (1941) provided the first geological map of the eastern part of the Ghost Lake Batholith at a scale of 1:63 360. More recently, reconnaissance and detailed mapping at scales of 1:63 360 and 1:31 680 by Breaks *et al.* (1976a, 1976b), Breaks *et al.* (1978), and Breaks and Kuehner (1984) has delineated the phases of the Ghost Lake Batholith.

Breaks *et al.* (1978) hypothesized that rare metal pegmatites in the Mavis Lake area were geochemically fractionated apophyses originating from this batholith.

GEOLOGICAL SETTING

The greisen vein system is located at the southeastern contact of the Ghost Lake Batholith, a highly evolved, S–type, peraluminous granitoid complex (Breaks *et al.* 1985). The alteration zone is developed in amphibolitized mafic metavolcanics (Central Volcanic Belt of the Wabigoon Subprovince; Trowell *et al.* 1980), which correspond to the beryl zone of the regionally–zoned Mavis Lake rare metal pegmatite group (Breaks *et al.* 1985). The Zealand occurrence appears to fall within the "amphibolite greisen formation" of Shcherba's classification of greisens (1970, p.250).

The greisen vein system is mostly conformable to host rock foliations and is traceable for at least 0.65 km eastwards from the contact between the metavolcanics and the Ghost Lake Batholith. It varies from 1.5 to 10 m in width. Figure 11.2 is a detailed (1:50 scale), geological map of the well–exposed westernmost part of the vein system, where direct linkage with the Ghost Lake Batholith can be observed.

GEOLOGICAL AND GEOCHEMICAL FEATURES OF ASSOCIATED PEGMATITIC GRANITIC ROCKS

The pegmatitic granites exposed on, and near, the Petrunka property form the most geochemically advanced and lithologically diverse portion of the entire Ghost Lake Batholith. Geochemical evolution is illustrated by the inter–element ratios of potassic feldspars from potassic pegmatites: K/Rb = 43 to 59, K/Cs = 121 to 341, K/Ba = 4650 to >9050, Rb/Sr = 60 to 84, and Ba/Rb = 0.014 to <0.0046 (Breaks, in preparation). The lithological diversity is illustrated by Table 11.1, which lists the primary and replacement units identified on the property. Modal analyses of most of these units are given in Table 11.2.

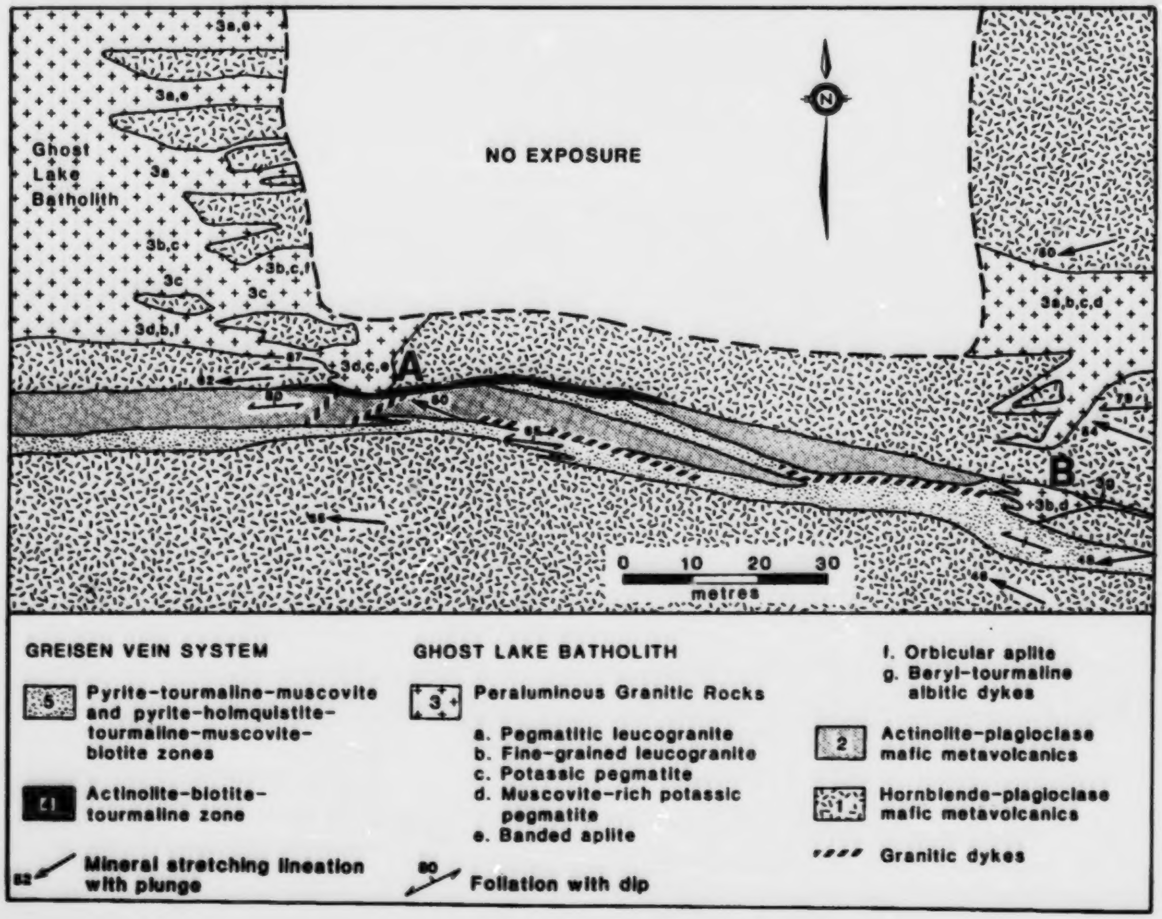
3a,e
3a,e
Ghost Lake Batholith
3a
3b,c
3b,c,f
3c
3c
3d,b,f
3d,c,e
A
NO EXPOSURE
N
80
3a,b,c,d
B
3b,d
0 10 20 30
metres
GREISEN VEIN SYSTEM
5 Pyrite–tourmaline–muscovite and pyrite–holmquistite–tourmaline–muscovite–biotite zones
4 Actinolite–biotite–tourmaline zone
82 Mineral stretching lineation with plunge
GHOST LAKE BATHOLITH
3 Peraluminous Granitic Rocks
a. Pegmatitic leucogranite
b. Fine–grained leucogranite
c. Potassic pegmatite
d. Muscovite–rich potassic pegmatite
e. Banded aplite
f. Orbicular aplite
g. Beryl–tourmaline albitic dykes
2 Actinolite–plagioclase mafic metavolcanics
1 Hornblende–plagioclase mafic metavolcanics
Granitic dykes
80 Foliation with dip

Figure 11.2. *Detailed geology of the exogreisen vein system at the Petrunka Property.*

TABLE 11.1. MINERALOGY OF PRIMARY AND REPLACEMENT UNITS OF THE GHOST LAKE BATHOLITH ON THE PETRUNKA PROPERTY. TERMINOLOGY OF THE PRIMARY UNITS IS MODIFIED FROM CERNY *ET AL.* (1981, p.50), AND TERMINOLOGY OF THE REPLACEMENT UNITS IS BASED IN PART ON SHCHERBA (1970).

UNIT	MINERAL ASSEMBLAGE
	PRIMARY UNITS
Pegmatitic Leucogranite	tourmaline-muscovite-albite-quartz-K-feldspar
Fine-grained Leucogranite	garnet-tourmaline-K-feldspar-quartz-albite
Muscovite-rich Potassic Pegmatite*	garnet-tourmaline-muscovite-albite-K-feldspar-quartz
Banded Aplite	tourmaline-garnet-muscovite-quartz-albite
Orbicular Aplite**	tourmaline-muscovite-K-feldspar-quartz albite
	REPLACEMENT UNITS
Autometamorphic Greisen	cassiterite-chrysoberyl-albite-beryl-muscovite
Albitized Potassic Pegmatite	garnet-tourmaline-quartz-albite
Albitic Dikes	quartz-beryl-tourmaline-albite
Marginal Exogreisen	quartz-albite-actinolite-biotite-tourmaline

** 30-35% muscovite in the matrix, between single crystals and aggregates of blocky K-feldspar.*

*** a type of primary aplite, characterized by ovoid, proto-orbicules (Leveson 1966) of fine grained tourmaline-green muscovite- albite in a coarse matrix of K-feldspar-albite-green muscovite.*

TABLE 11.2. MODAL ANALYSES OF PRIMARY AND REPLACEMENT UNITS OF THE GHOST LAKE BATHOLITH ON THE PETRUNKA PROPERTY. SEE TABLE 11.1 FOR DEFINITION OF UNITS.

	PRIMARY UNITS				REPLACEMENT UNITS			
	Pegmatitic Leucogranite[1]	Muscovite-rich Potassic Pegmatite[1]	Fine-grained Leucogranite[2]	Potassic Pegmatite[1]	Autometamorphic Griesen[1]	Granitic Pegmatite Dike[1]	Albitized Potassic Pegmatite[1]	Albitized, Fine-grained Leucogranite[2]
Quartz	31.5	35.2	28.6	23.8		3.5	21.6	26.4
Plagioclase	19.2	22.7	57.4	30.8	5.0	56.5	73.1	48.5
K-Feldspar	42.5	27.3	11.4	41.3				20.9
Muscovite	5.5	13.6	0.4		85.0		0.5	0.5
Tourmaline	1.4	1.1	2.2	1.4		8.2	4.9	3.8
Garnet		X	X				X	X
Beryl				X	10.0	31.8		
Cassiterite					X			
Chrysoberyl					X			

X - present in trace amounts

[1] *Analyses done on clean fresh outcrop surfaces covering a 3 by 3 m area and 5 cm grid spacing for the coarse-grained primary units and 0.5 by 0.5 m area and 1 cm grid spacing for the relatively finer-grained replacement units.*

[2] *Thin section modal analysis.*

Incipient development of albitization replacement units in the pegmatitic granites was observed in two settings: a) along contacts between the batholith and amphibolitized mafic metavolcanics; and b) in an exocontact dike network. In the first setting, replacement occurs as a 10 to 100 cm wide garnet–muscovite–tourmaline–quartz–albite border unit containing about 73 percent albite. Textures indicate

Photo 11.1. *Transition from albite-beryl-muscovite autometamorphic greisen (G) into bifurcating beryl-tourmaline-albite exocontact dikes (D) at Locality B in Figure 11.2.*

a progressive degradation of blocky potassic feldspar in a beryl–tourmaline–muscovite potassic pegmatite as the batholith contact is approached. This disappearance of potassic feldspar is complemented by a biotite–rich halo in the adjacent amphibolitic host rocks, which also suggests a metasomatic origin for this albite–rich unit. The exocontact dikes (Photo 11.1) are 10 to 30 cm wide, and are abundant in one locality (B, Figure 11.2). These rocks normally consist of a tourmaline–quartz–albite assemblage which can grade along strike into berylliferous albitite (Table 11.2), or can interconnect with pyrite–tourmaline–quartz veins, locally containing small pods (up to 50 cm by 100 cm) of approximately 90 percent beryl. Skeletal tourmaline intergrowths with albite are another notable textural feature on the property, and can occur in albitized marginal plutonic units of the Ghost Lake Batholith or in tourmaline–albite exocontact dikes.

Apparently, fluids emanating from these replacement units interacted chemically with amphibolitic mafic metavolcanic host rocks, resulting in complementary 1 to 5 cm wide, brown weathering selvedges enriched in K_2O, Li, Rb, Cs, F, and Sn (Table 11.3). However, most fluids were probably channeled in the host rocks to locality A in Figure 11.2, which represents the beginning of the greisen vein system.

AUTOMETAMORPHIC GREISEN

Autometamorphic greisens occur as local lenses up to 4.5 m by 0.42 m, as at locality B (Figure 11.2, Photo 11.1). These units are enclosed within, and are gradational into, a small exocontact pegmatitic granite lens (3 m by 14 m) composed of albitized, muscovite–rich potassic pegmatite which envelopes a core of fine–grained leucogranite. The eastern end of a muscovite–rich potassic pegmatite unit grades into albite–rich dikes with black tourmaline selvedges. These dikes also contain appreciable beryl (Table 11.2). The western end of this pegmatitic granitic pod grades into a similar muscovite–rich greisen, which contains appreciable pyrite, tourmaline, and biotite.

The greisen pods are strongly foliated and lineated, fine to coarse grained, and yellow–green due to the presence of 85 percent muscovite. They contain appreciable beryl, which occurs as white and light grey, euhedral to subhedral crystals up to 1.2 cm long (normal to c–axis) and 0.7 cm by 2.5 cm (parallel to c–axis). Lesser amounts of anhedral albite and accessory chrysoberyl and cassiterite are also present (Table 11.2). Chrysoberyl (Al_2BeO_4), which occurs as 1 to 2 mm yellow–green anhedral grains, is a relatively rare mineral in pegmatitic rocks and is apparently restricted to desilicated or contaminated pegmatites (Burt 1982, p.139).

EXOGREISEN VEIN SYSTEM

The exogriesen forms a bifurcating vein system which is in contact with the pegmatitic granite at two points (localities A and B, Figure 11.2). The vein system mainly straddles the lithological contact between black, hornblende–plagioclase amphibolites, and green, mafic to intermediate, actinolite–plagioclase–bearing metavolcanics. A subordinate branch crosses the metavolcanics, establishing a direct link with the pegmatitic granites at locality A. The mineralogy of this branch changes systematically with increasing distance from the batholithic contact: from a) biotite ± actinolite ± tourmaline ± quartz ± albite (CI 90 to 95); to b) albite + quartz + tourmaline (CI 80 to 90); to c) tourmaline + pyrite + albite + holmquistite + chlorite + actinolite + biotite (CI 70); and finally to d) tourmaline + chlorite + albite + chlorite + pyrite (CI 50 to 60).

The exogriesen vein system begins as a 60 m long by 2 to 3 m wide, highly mafic, actinolite–biotite–tourmaline zone (Unit 4, Figure 11.2, and Photo 11.2), which is tangential to the batholithic contact at Locality A. However, most of the vein system is a tourmaline–pyrite–muscovite unit (Unit

TABLE 11.3. PARTIAL GEOCHEMICAL ANALYSES OF CONTACT METASOMATIC SELVEDGES AND GREISEN MATERIAL FROM THE PETRUNKA PROPERTY. CONCENTRATION IN PARTS PER MILLION UNLESS OTHERWISE INDICATED. ANALYSES BY GEOSCIENCE LABORATORIES, ONTARIO GEOLOGICAL SURVEY, TORONTO.

ALTERATION TYPE	Sample No.	F	Li	Rb	Cs	Be	Sn	Nb	Ta	W	K_2O	Na_2O
CONTACT METAMSOMATIC ROCKS												
Albite-biotite selvedge	88FWB-1	4100	1860	2476	702	17	147	14	<10	<50	4.48%	0.53%
Albite-biotite selvedge	GLB84-1	2900	1490	2460	595	10	65.9	21	11	<50	2.72%	
AUTOMETAMORPHIC GREISEN												
Cassiterite-chryosoberyl-albite-beryl-green muscovite greisen	GLB88-20	1800	303	3370	195	1000	440	65	91	<50	7.42%	1.48%
Pyrite-muscovite-biotite-plagioclase	GLB88-24		1050	1915	670	25		16	<10	<50		
EXOGRIESEN												
Plagioclase-rich rock with porphyroblasts of holmquistite, actinolite, biotite and chlorite	GLB88-5A	350	1960	128	170	2	2.3	<5	<10	<50	0.55%	3.66%
	GLB88-5B	400	1340	128	170	2	2.3	7	<10	<50	0.57%	2.81%
	GLB88-8A	470	2450	270	340	2	2.9	<5	<10	<50	1.09%	2.78%
	GLB88-9A	320	1020	190	220	2	1.6	6	<10	<50	0.80%	3.60%
	GLB88-9B	290	1480	210	235	2	1.5	<5	<10	<50	0.76%	3.85%
Albite-tourmaline-muscovite rock	GLB88-22	650	178	169	26	<1	3	5	<10	<50	4.9%	1.54%
Actinolite-biotite-tourmaline rock in mafic-rich, marginal sub-unit	88FWB-14	1.30%	1270	1950	915	9	52	<5	<10	<50	6.01%	0.42%
	GLB84-3	1.78%	1400	1860	755	6	142	7	<10	<50		

Photo 11.2. *Actinolite-biotite-tourmaline marginal unit of the main exogreisen vein system (Unit 4 in Figure 11.2).*

5, Figure 11.2), which is well foliated, fine to medium grained, has relatively sharp boundaries with its host, and is invariably rust-stained. The remainder of the vein system is composed of an anastomosing network of smaller veinlets in actinolite-rich, mafic to intermediate, metavolcanic rocks or in a holmquistitebiotite-actinolite-plagioclase rock (Photo 11.3). The veinlets conceivably developed during the same fluid transmittal event as the larger units of the vein system, since they also contain holmquistite and biotite. The veinlets occur up to 5.5 m from the larger veins.

Both scales of the vein system are cross-cut by tourmaline-quartz-albite dikes (10 to 30 cm in width), which locally contain light blue to white beryl. These dikes are planar or moderately boudinaged.

Photo 11.3. *Interconnected holmquistite-biotite-plagioclase veinlets near the actinolite-biotite-tourmaline marginal zone. This veinlet system is post-dated by a tourmaline-quartz-albite dike in the lower right corner.*

HOLMQUISTITE DISTRIBUTION

Holmquistite is readily recognized in the field, where replacement of the precursor amphibole has been relatively complete (type locality 4 below), by a distinctive violet cast. More commonly, however, the distinctive violet colours are muted by a complex intergrowth of the holmquistite with biotite, chlorite, tourmaline, actinolite, and anthophyllite. Field recognition in this situation demands close inspection with a hand lens on clean, rust–free exposures.

Holmquistite on the Petrunka property occurs in grains ranging from fine–grained sections approximately parallel to the c–axis up to 1.5 cm by 7 cm in size. Holmquistite was observed in four specific settings, within and proximal to the exogreisen vein system:

1. with biotite–actinolite–plagioclase and plagioclase–biotite–iron–oxide in a system of closely–spaced, anastomosing, 1 to 3 cm wide veinlets which are hosted in actinolite–rich, mafic to intermediate metavolcanics (Photo 11.3)
2. with actinolite, anthophyllite, biotite, and chlorite in porphyroblastic segregations developed in a medium– to coarse–grained biotite–plagioclase rock of possible clastic metasedimentary origin (Photo 11.4)
3. with pyrite, biotite, tourmaline, and albite in a unit traceable for at least 650 m within the main exogreisen vein system
4. in thin biotite–holmquistite sheets, oriented at a high angle to foliation and situated 2 m from the main exogreisen vein system.

These occurrences suggest that lithium was expelled from the Ghost Lake Batholith in several episodes. Holmquistite in the type 3 occurrence, in the main exogreisen zone, has a well–developed mineral lineation (287°/53°), concordant to the regional lineation. In type 1 and 2 occurrences, holmquistite is randomly oriented on foliation surfaces and probably developed after the regional lineation. Type 4 holmquistite is obviously younger than this deformation event: however, its temporal relations with types 1 and 2 are uncertain.

Multiple generation events for holmquistite have also been suggested elsewhere. For example, Morgan and London (1987) suggested that three holmquistite–generating events can be developed in exomorphic haloes as around the Tanco Pegmatite further west in the Bird River Greenstone Belt of Manitoba.

Formation of types 1, 2, and 3 holmquistite occurrences is post–dated by several planar to slightly boudinaged, albite–rich dikes (Photo 11.3). These garnet–tourmaline–quartz–albite dikes vary from 10 to 30 cm in width and locally contain light blue to white beryl. Biotite–rich selvedges, 1 to 4 cm in width, overprint the type 1 holmquistite–bearing veinlet system.

GEOCHEMISTRY

Listed in Table 11.3 are 11 partial analyses from autometamorphic and exogreisen material, and

Photo 11.4. *Porphyroblastic segregations of coarse-grained, anthophyllite, actinolite and biotite developed in a medium-grained chlorite-biotite plagioclase rock situated along the southern contact of Unit 4 (Figure 11.2) at its westernmost exposure.*

biotite–rich selvedges related to the Ghost Lake Batholith.

Fluorine contents range from 0.029 to 1.8 percent, which overlap the lower range for greisen rocks reported by Bailey (1977). Fluorine is probably partitioned into biotite, tourmaline, and holmquistite, since fluorite or topaz were not observed. The highest fluorine contents (1.33 and 1.78 percent) occur within the highly mafic, marginal unit (Unit 4, Figure 11.2).

Rare alkali metal abundances (lithium, cesium, and rubidium) also indicate significant geochemical fractionation. Maximum concentrations of these three elements are, respectively, 204, 350, and 43 times their Clarke values.

Tin concentrations vary greatly (2 to 400 ppm), with greatest enrichment in the albite–beryl–muscovite autometamorphic greisen which contains accessory cassiterite and chrysoberyl (Table 11.2). This unit also has the highest rubidium content (3370 ppm) and substantial fractionation of tantalum over niobium (niobium/tantalum = 0.71, compared to an average crustal ratio of about 12).

EXPLORATION SIGNIFICANCE OF HOLMQUISTITE

Holmquistite has been documented by previous investigators as occurring exclusively in exomorphic haloes around lithium–rich, rare metal pegmatites (Heinrich 1965; Trueman and Cerny 1982; London 1986). In these occurrences, the holmquistite formed in response to reaction of a lithium–rich fluid with amphibolitic mafic country rocks. Such fluids were released at the late magmatic–hydrothermal evolutionary stages of spodumene– and/or petalite–bearing pegmatites (Morgan and London 1987).

Other studies have also indicated that holmquistite has a marked tendency to occur in proximity to lithium–rich pegmatites. Cerny *et al.* (1981, p.101), for example, noted the restriction of holmquistite to within 20 m of pegmatite contacts in the Cat Lake–Winnipeg River Pegmatite District. Morgan and London (1987) found holmquistite no farther than 4.5 m above the flat–lying, highly fractionated, Tanco lithium–cesium–rubidium–tantalum–beryllium Pegmatite. Shearer and Papike (1988) documented holmquistite only up to 5 m from the Edison Pegmatite of South Dakota. Breaks (in preparation) recognized holmquistite within 2 m of sub–vertical, spodumene pegmatite dikes in the Dryden Pegmatite Field. Due to this close spatial association with highly fractionated, lithium–rich, rare metal pegmatites, holmquistite has been proposed as a typomorphic indicator mineral in exploration for such deposits (Trueman and Cerny 1982, p.475; London 1986).

This study documents a significant newly discovered occurrence of holmquistite. It is genetically linked with a fertile pegmatitic granite (the Ghost Lake Batholith), which exhibits marginal and exocontact greisenization and albitization, and is spatially removed from the spodumene pegmatites of the Mavis Lake Group. The formation of the Zealand Township holmquistites, thus, has no direct affiliation with those pegmatites, since their nearest exposure is 4.6 km to the east. Therefore, this holmsquistite occurrence suggests that the utilization of holmquistite as a typomorphic mineral in exploration programs must be undertaken with caution. While still useful as an indicator of rare metal mineralization, some care should be taken when attempting to use holmquistite in the establishment of drill targets designed to intersect blind, rare metal pegmatites enriched in lithium, tantalum, rubidium, and cesium. The best approach would be to integrate holmquistite distribution data with various geophysical, geochemical, and geological parameters.

The author suggests that similar holmquistite occurrences may be found in other pegmatite fields of the intermediate and shallow depth divisions of the classification of Ginsburg *et al.* (1979), where contact zones of fertile pegmatitic granite complexes are exposed.

RECOMMENDATIONS FOR FUTURE EXPLORATION

The geological observations and preliminary geochemical results indicate that extensive transport of rare metals, fluorine, boron, and quite likely tungsten, manifested during late–kinematic greisenization and albitization of an Archean peraluminous "fertile" granite. More exploration is required to define the greisen vein system more fully, as there may be *en echelon* or interconnecting vein sets.

These rocks may contain economic concentrations of tin, tungsten, lithium, rubidium, cesium, tantalum, and beryllium. The presence of gold should also be considered in such zones. Breaks *et al.* (1986, p.376–377) revealed an association of this metal with albitized, peraluminous granitoid dikes in the North Caribou Lake Greenstone Belt in the Sachigo Subprovince.

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12. Project Number 88–21. Geology of the Tectonic Boundary Zone Between the English River and Winnipeg River Subprovinces, Northwestern Ontario

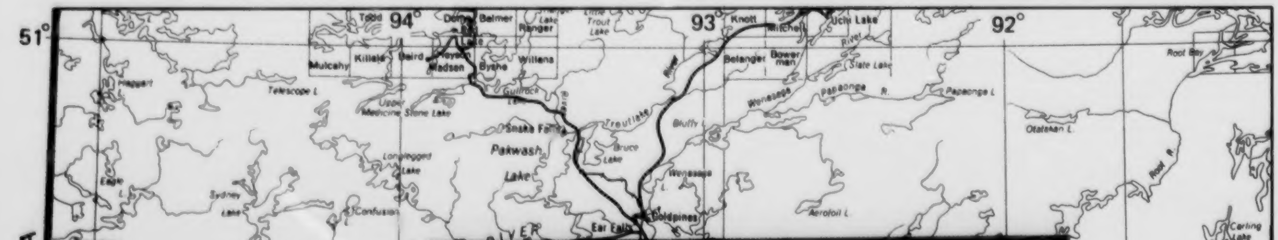
Mary Sanborn-Barrie

Geologist, Precambrian Geology Section, Ontario Geological Survey, Toronto.

INTRODUCTION

Regional mapping in northwestern Ontario by Breaks *et al.* (1978) established that the gneissic terrane situated between the Wabigoon and Uchi granite–greenstone subprovinces can be broadly divided into a northern supracrustal metasedimentary terrane known as the English River Subprovince (ERS), and a southern intrusive and gneissic granitoid terrane known as the Winnipeg River Subprovince (WRS) (Card and Ciesielski 1986).

As part of an ongoing program by the Ontario Geological Survey to investigate the geologic characteristics of subprovince boundaries, this study focuses on the boundary between the ERS and the WRS, referred to here as the English River/Winnipeg River boundary (ER/WR boundary). Specifically, lithologic, structural and metamorphic relationships are being investigated in metasedimentary, metavolcanic, and plutonic rocks along a 300 km strike length of the ER/WR boundary and adjoining segments of these subprovinces (*see* Figure 12.1). A


51°
94°
93°
92°
50°
MANITOBA
Pakwash Lake
Ear Falls
Goldpines
Uchi Lake
Trout Lake
Lac Seul
Vermilion River
Wabigoon
Minnitaki
Eagle Lake
Dryberry L.
Upper Manitou L.
Aulneau Peninsula
KENORA

[redacted]

Figure 12.1. *Location map for the English River–Winnipeg River subprovince boundary area, Northwestern Ontario. Scale: 1:1 584 000 or 1 inch to 25 miles.*

major aim of this study is to understand the structural history and boundary conditions of the ERS and the WRS, and in so doing, to increase understanding of large-scale tectonics in rocks of Archean age. An equally important goal is to contribute to the geologic data base for this part of northwestern Ontario by outlining previously unknown volcanic stratigraphy, and by providing a structural framework in which to consider local and regional structures (such as folds, fabrics, and shear zones). As well, a re-evaluation of the mineral potential of this structurally complex region focuses on stratiform base metal potential in the Separation Lake metavolcanics, and the potential for gold mineralization within the transpressional tectonic regime of the ER/WR boundary, a structural setting not dissimilar to those of major gold camps elsewhere in the Superior Province (Colvine *et al.* 1988; Sibson *et al.* 1988).

The study area is bounded by latitudes 50°15′N and 50°35′N and longitudes 91°40′W and 95°05′W. Access to the area is gained primarily by the English River water system, extending from Umfreville Lake in the west, to the eastern part of Lac Seul. Most lakes along this water system are accessible by road. In addition, several northerly trending roads transect the study area. These include the English River Road (north from the community of Redditt), the Jones Road (north from the Kenora airport) and the Red Lake Road (Highway 105). Mapping was carried out at a scale of 1:100 000.

PREVIOUS WORK

The English River and Winnipeg River subprovinces were previously examined during a five-year, reconnaissance mapping program initiated in 1973 by the Ontario Geological Survey. From this program, preliminary geological maps were completed at scales of 1:126 720 (Operation Ignace-Armstrong, Sage *et al.* 1974) and 1:63 360 (Operation Kenora-Ear Falls, *see* Breaks *et al.* 1978).

GENERAL GEOLOGY

The general geology of the area is shown in Figure 12.2 and is taken from a compilation by Breaks *et al.* (1978) and Breaks and Bond (in preparation).

THE ENGLISH RIVER SUBPROVINCE (ERS)

The ERS consists primarily of a migmatized sequence of feldspathic wacke and pelite. All degrees of migmatization, as classified by Brown (1973), are present; however, metatexite (10 percent to 70 percent mobilizate) is the most common migmatite type in the ERS. At most localities, migmatization does not obscure the thickness of individual sedimentary beds. Feldspathic wacke is typically thickly to very thickly bedded (40 cm to 1.5 m), whereas pelitic horizons are generally thin to medium bedded (4 cm to 40 cm). Determinations of the younging direction of bedding at numerous localities throughout the southern part of the ERS indicate overall younging to the north.

The mineralogy of wacke/pelite metatexite throughout the ERS reflects changes in metamorphic grade, which varies from amphibolite to granulite facies. In addition to an ubiquitous assemblage of plagioclase + quartz + biotite±muscovite, commonly observed metamorphic minerals include garnet, cordierite, sillimanite, and, less commonly, clinopyroxene and orthopyroxene. Aspects of the thermal history and metamorphic conditions of the ERS are discussed by Breaks *et al.* (1978), Chipera and Perkins (1988), Breaks and Bond (in preparation), and Breaks (this volume).

Several occurrences of thickly bedded, polymictic conglomerate up to 40 m wide occur at, and close to, the southern margin of the ERS. Three major occurrences, north of Separation Lake, at Oak Lake, and at Perrault Lake, are indicated in Figure 12.2. At each locality, the conglomerate incorporates clasts derived from lithologic units exposed to the immediate south. Clast types include mafic, intermediate, and felsic volcanics, homogeneous, massive to foliated granitoids, oxide- and silicate-facies ironstone, and minor quartzose wacke and chert. Units of massive, ungraded, quartzose and feldspathic wacke (10 cm to 50 cm wide) are interbedded with the conglomerate.

Intrusive rocks within the ERS include granites and pegmatites with the chemical and mineralogical attributes of S-type granites generated by anatexis of metasedimentary rocks (Breaks *et al.* 1978). Deposits of tantalum, lithium, and beryllium are associated with some of these intrusions (Figure 12.2).

SEPARATION LAKE GREENSTONE BELT

Metavolcanic rocks and subordinate mafic intrusive rocks are locally exposed along the ER/WR boundary and appear to form a discontinuous screen that separates the two subprovinces (Figure 12.2). The Separation Lake Greenstone Belt (SLGB) is one of the largest segments of this discontinuous metavolcanic screen and is considered part of the WRS in this study. This belt attains a strike length of some 50 km, a horizontal width of 5 km, and is the eastern extension of the Bird River Greenstone Belt (McRitchie and Weber 1971) in Manitoba (Figure 12.2). The SLGB comprises predominantly massive to pillowed mafic volcanics, commonly with interbedded oxide- or silicate-facies ironstone. Intermediate and felsic volcanics are subordinate and generally occur along the northern margin of the belt.

Mafic and intermediate volcanic rocks occur sporadically along the ER/WR boundary to western Lac Seul, a distance of nearly 100 km (Figure 12.2). These units are interpreted as remnants of the SLGB. In areas where these metavolcanic rocks occur, the boundary between the ERS and the WRS

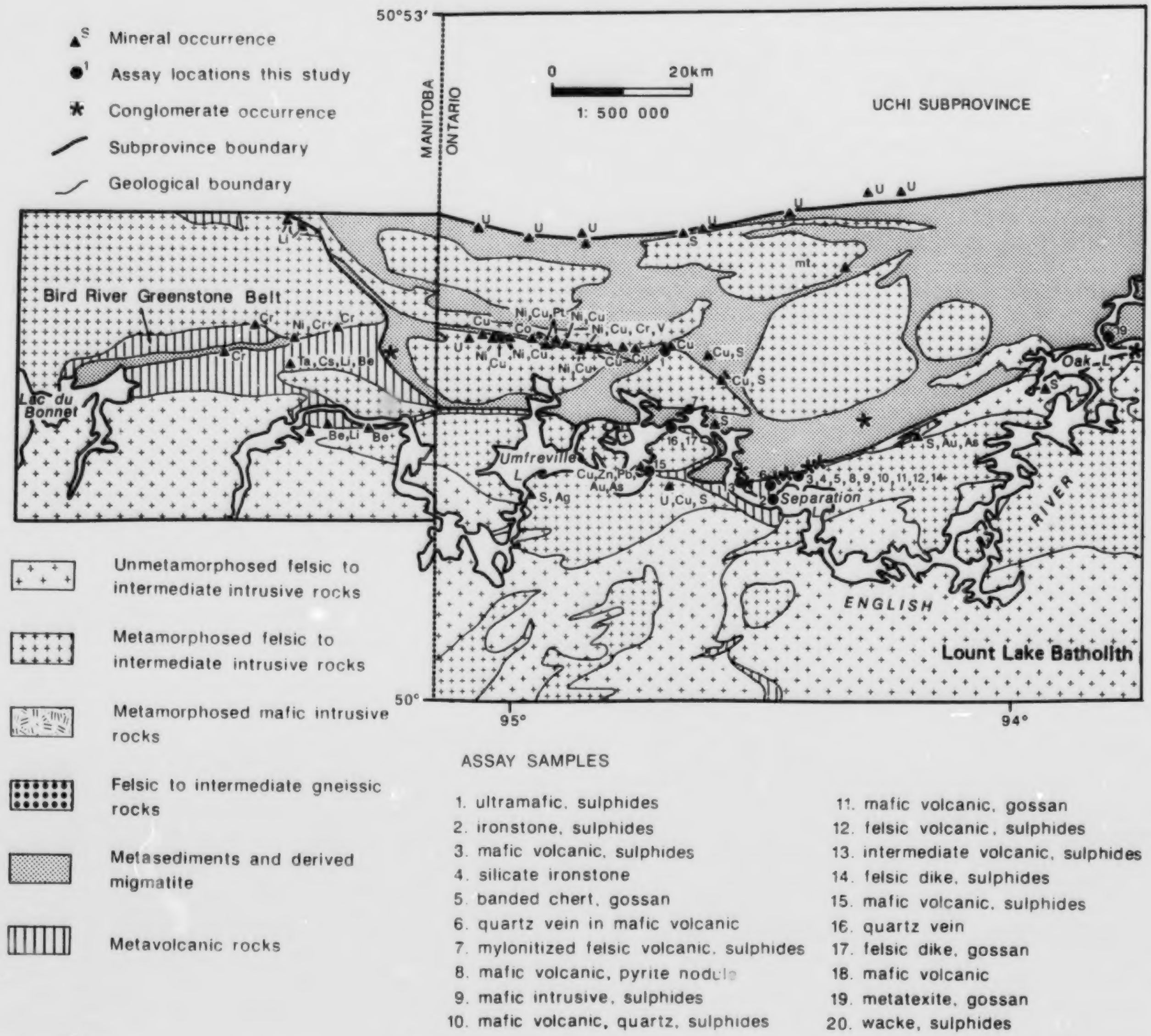
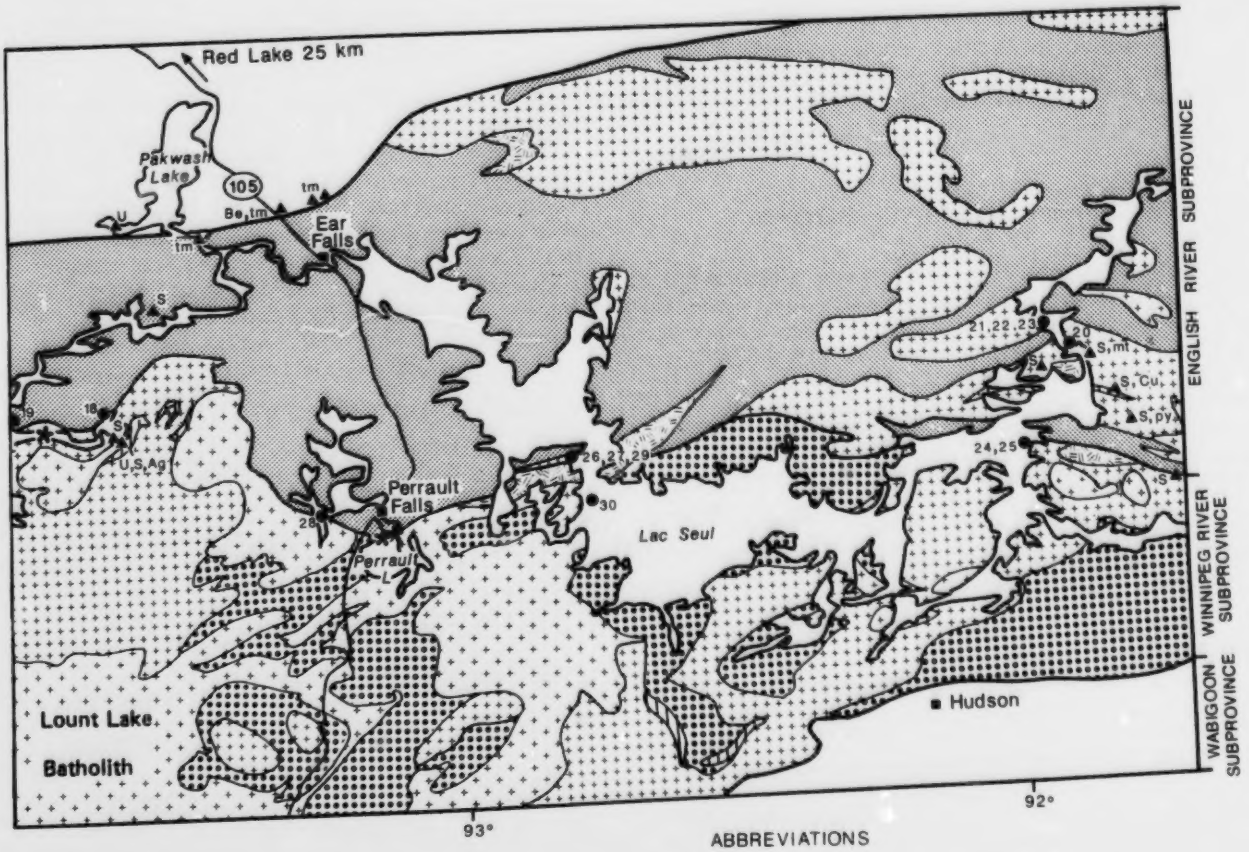

Mineral occurrence
Assay locations this study
Conglomerate occurrence
Subprovince boundary
Geological boundary
50°53′
MANITOBA
ONTARIO
0
20km
1: 500 000
UCHI SUBPROVINCE
Bird River Greenstone Belt
Lac du Bonnet
Umfreville L.
Separation
Oak L.
ENGLISH
RIVER
Lount Lake Batholith
U
Li
Cr
Ni,Cr
Ta,Cs,Li,Be
Be,Li
Be
Ni,Cu,Pt
Ni,Cu
Ni,Cu,Cr,V
Cu
Co
Cu,S
S
mt
Cu,Zn,Pb,Au,As
S,Ag
U,Cu,S
S,Au,As
3,4,5,8,9,10,11,12,14
16,17
15
19
50°
95°
94°
Unmetamorphosed felsic to intermediate intrusive rocks
Metamorphosed felsic to intermediate intrusive rocks
Metamorphosed mafic intrusive rocks
Felsic to intermediate gneissic rocks
Metasediments and derived migmatite
Metavolcanic rocks
ASSAY SAMPLES
1. ultramafic, sulphides
2. ironstone, sulphides
3. mafic volcanic, sulphides
4. silicate ironstone
5. banded chert, gossan
6. quartz vein in mafic volcanic
7. mylonitized felsic volcanic, sulphides
8. mafic volcanic, pyrite nodule
9. mafic intrusive, sulphides
10. mafic volcanic, quartz, sulphides
11. mafic volcanic, gossan
12. felsic volcanic, sulphides
13. intermediate volcanic, sulphides
14. felsic dike, sulphides
15. mafic volcanic, sulphides
16. quartz vein
17. felsic dike, gossan
18. mafic volcanic
19. metatexite, gossan
20. wacke, sulphides

Figure 12.2. *Generalized geology of the English River–Winnipeg River subprovince boundary and adjoining regions. After Breaks et al. (1978) and Breaks and Bond (in preparation).*

is interpreted as the northern margin of the metavolcanic belt (or its remnants). This interpretation is supported by structural relationships at the boundary (see below).

MINERALIZATION IN THE SLGB

Several occurrences of intermediate and felsic volcanic rocks along the ER/WR boundary, not distinguished from metasedimentary rocks of the ERS during previous mapping, appear to have a potential for base metal mineralization. These lithologies are highly strained and tectonically layered, making interpretation of primary textures difficult. However, these units have several important features commonly associated with base metal mineralization. Tabular and possibly stratiform lenses of disseminated sulphides occur, with up to five percent pyrite and two percent chalcopyrite, in metavolcanic rocks. One zone of intense tourmalinization (up to 15 percent tourmaline) is present in intermediate metavolcanics that are interlayered with chlorite–biotite–garnet units (interflow metasediments?). This zone was traced parallel to the main easterly trending structural fabric for 50 m, to an area of no exposure due to glacial cover. Local quartz–tourmaline–pyrite


Red Lake 25 km
Pakwash Lake
105
tm
Be,tm
U
tm
Ear Falls
S
18
S
U,S,Ag
9
28
Perrault Falls
Perrault L.
26,27,29
30
Lac Seul
21,22,23
20
S,mt
S
S,Cu
S,py
24,25
S
Hudson
Lount Lake Batholith
93°
92°
ENGLISH RIVER SUBPROVINCE
WINNIPEG RIVER SUBPROVINCE
WABIGOON SUBPROVINCE

21. gossan
22. gossan
23. gossan
24. mylonite, altered, sulphides
25. mylonite, altered, sulphides
26. intermediate volcanic, tectonized, quartz veins
27. crack-seal quartz vein
28. mafic volcanic, silicified, sulphides
29. crack-seal quartz vein
30. mafic volcanic, sulphide tension gash

ABBREVIATIONS

Elements

Ag	Silver
As	Arsenic
Au	Gold
Be	Beryllium
Cr	Chromium
Cs	Cesium
Cu	Copper
Li	Lithium
Ni	Nickel
Pb	Lead
Pt	Platinum
Ta	Tantalum
S	Sulphur
U	Uranium
Zn	Zinc
V	Vanadium

Minerals

mt	magnetite
py	pyrite
tm	tourmaline

Figure 12.2. continued.

fracture filling cuts this zone. South of the tourmalinized zone, a deformed diorite intrusion lies within this remnant of the SLGB and apparently has undergone the same deformation history as has the tourmalinized metavolcanic units. Tourmaline (particularly the Mg-rich variety dravite) is a common gangue mineral in the metamorphosed strata-bound massive sulphide deposits of the Appalachian–Caledonian Orogen, and has been proposed to be a valuable prospecting guide in the search for massive sulphide deposits (Taylor and Slack 1984). A comparable geologic setting for base metal mineralization with similar alteration patterns has been noted elsewhere in Ontario (e.g. Gagne Lake Prospect, Rainy Lake area; Poulsen 1984).

Late-tectonic quartz veins, locally containing pyrite and tourmaline, cut highly strained metavolcanic rocks at the ER/WR boundary. These veins typically occur in steeply dipping, easterly trending shear zones. They are up to 20 cm wide and can be traced along strike for up to 3 m. They typically display crack-seal texture, indicating repeated episodes of fracturing and fluid flow, a feature commonly associated with mesothermal gold mineralization.

Locations of assay samples collected during this study, primarily from tectonized metavolcanic rocks along the ER/WR boundary, are indicated in Figure 12.2.

THE WINNIPEG RIVER SUBPROVINCE

The Winnipeg River Subprovince (WRS) is characterized by felsic to intermediate plutonic and gneissic rocks of various ages. Reconnaissance mapping by Breaks *et al.* (1978) has shown that the WRS comprises three major rock suites (Figure 12.2):

1. the gneissic granitoid suite (pre–tectonic)
2. the sodic plutonic suite (pre– to syn–tectonic), and
3. the potassic plutonic suite (syn– to post–tectonic).

The northwestern part of the WRS examined in this study comprises predominantly homogeneous massive to foliated rocks of suites (2) and (3). In contrast, the northeastern part of the WRS comprises roughly equal proportions of the gneissic suite (1), and homogeneous plutonic rocks (2 and 3). In the study area, the gneissic granitoid suite is predominantly tonalitic in composition. Field relations indicate that gneissic rocks represent the oldest phases in the WRS (Breaks *et al.* 1978). U–Pb zircon dating by Krogh *et al.* (1976) indicated the presence of 3.0 Ga tonalite gneiss in the Lac Seul area of the WRS.

STRUCTURAL GEOLOGY

This investigation of the structural relationships between the ERS and the WRS involved documenting a variety of structural elements along the ER/WR boundary and adjoining segments of these subprovinces. Structural elements included bedding, gneissosity, schistosity, cleavage, lineations, folds, shear zones, and fractures. The structural data for an extensive part of the ER/WR boundary are presented in Figures 12.3, 12.4, and 12.5. From these figures, regional structural patterns can be recognized that characterize this subprovince boundary.

PLANAR TECTONIC ELEMENTS

Gneissosity is shown by solid– and dotted–line trajectories in Figure 12.3. In the ERS, gneissosity is regionally developed, steeply dipping (55° to 85°E), and trends northeasterly; whereas in the eastern part of the WRS, gneissosity trends northerly and northwesterly. Although not the most prominent planar fabric in the study area, gneissosity is the oldest recognized fabric (S_1). Development of S_1 is not necessarily coeval in the ERS and the WRS.

Schistosity (S_2) occurs as a prominent, planar, steeply dipping, easterly trending fabric throughout the ERS, the SLGB, and locally throughout the WRS. It is indicated by solid–line trajectories in Figure 12.3. Schistosity overprints, and therefore postdates, the less prominent S_1 fabric. S_2 is subparallel to the ER/WR boundary at most localities. Where the boundary is folded (to form a large-scale Z–fold), S_2 maintains an easterly trend and is axial planar to the fold. Where S_1 and S_2 are not recognized in the WRS, schistosity exhibits curvilinear trends

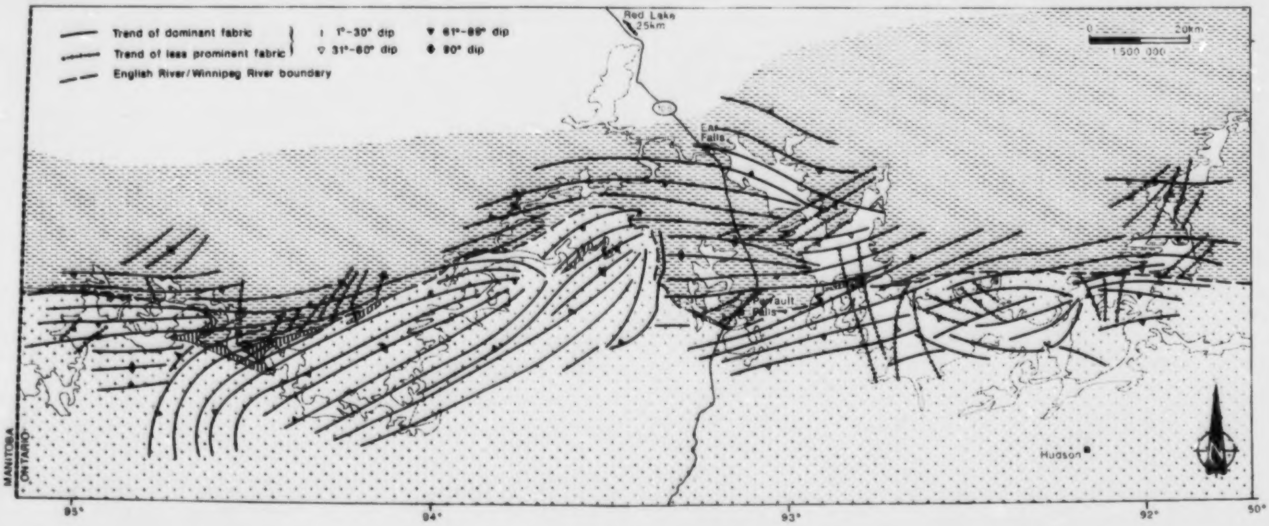


Figure 12.3. *Planar tectonic elements in the vicinity of the English River–Winnipeg River Subprovince boundary.*

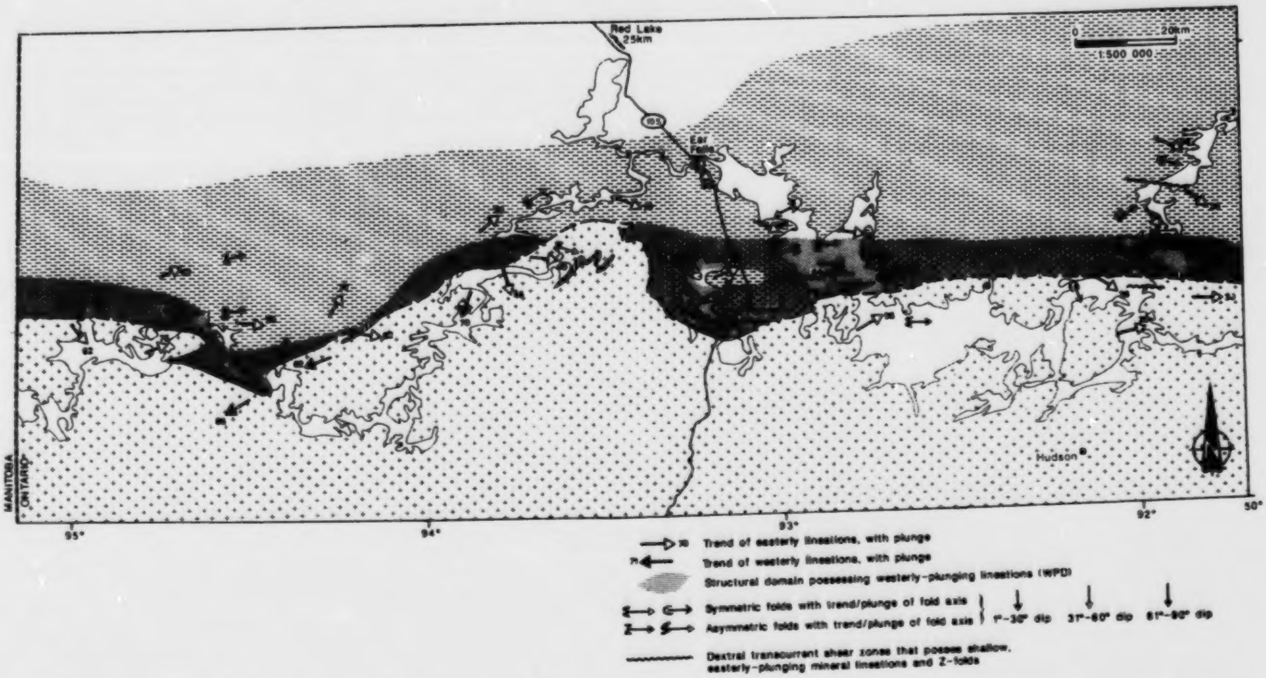

Red Lake
25km
0
20km
1:500 000
105
Ear Falls
Hudson
MANITOBA
ONTARIO
95°
94°
93°
92°
50°
Trend of easterly lineations, with plunge
Trend of westerly lineations, with plunge
Structural domain possessing westerly-plunging lineations (WPD)
Symmetric folds with trend/plunge of fold axis
Asymmetric folds with trend/plunge of fold axis
1°-30° dip
31°-60° dip
61°-90° dip
Dextral transcurrent shear zones that possess shallow, easterly-plunging mineral lineations and Z-folds

Figure 12.4. *Lineations and folds in the vicinity of the English River–Winnipeg River Subprovince boundary. Stippled zone corresponds to the structural domain of westerly plunging mineral lineations, referred to in text as westerly plunging domain (WPD).*

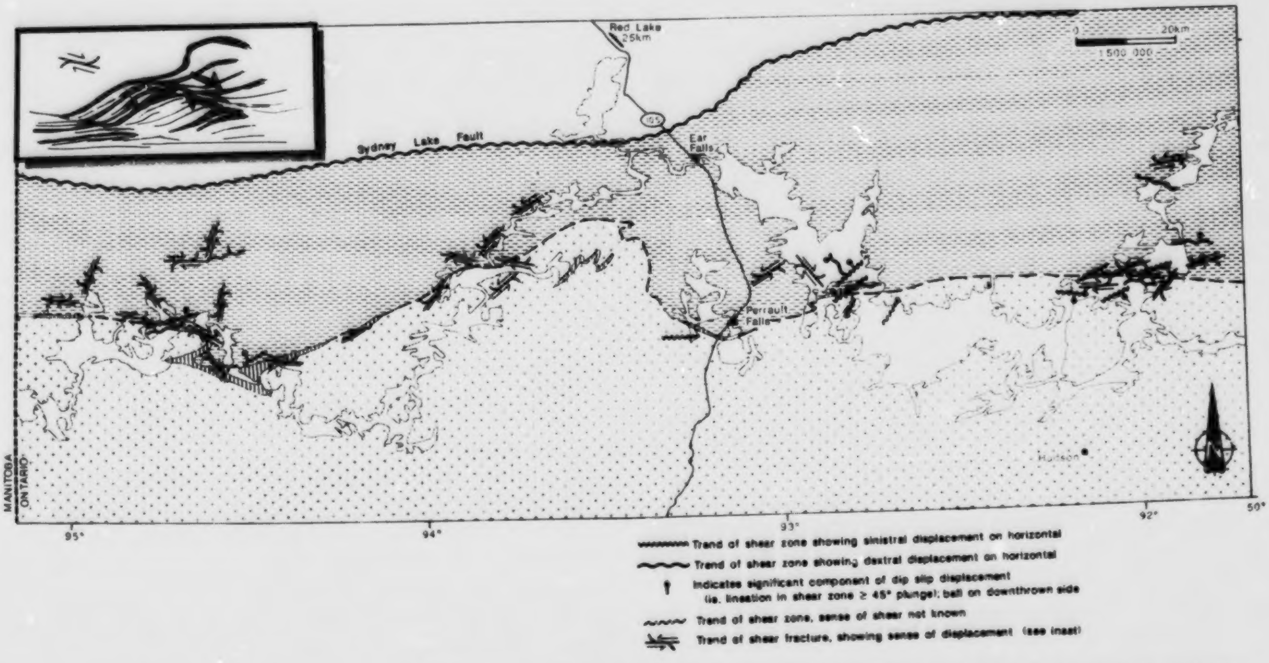

Red Lake
25km
0
20km
1:500 000
105
Sydney Lake Fault
Ear Falls
Perrault Falls
Hudson
MANITOBA
ONTARIO
95°
94°
93°
92°
50°
Trend of shear zone showing sinistral displacement on horizontal
Trend of shear zone showing dextral displacement on horizontal
Indicates significant component of dip slip displacement (ie. lineation in shear zone ≥ 45° plunge); ball on downthrown side
Trend of shear zone, sense of shear not known
Trend of shear fracture, showing sense of displacement (see inset)

Figure 12.5. *Deformation zones and shear fractures in the vicinity of the English River–Winnipeg River Subprovince boundary.*

which parallel the margins of post–tectonic plutons (Figure 12.3).

LINEATIONS

Lineation trends have been used with success to define major structural domains in polydeformed terranes (Stott 1986). In this study of the ER/WR boundary, three regional structural domains are distinguished on the basis of attitudes of mineral and dimensional lineations (Figure 12.4). Westerly plunging (55° to 70°) lineations occur within a 5 to 12 km wide domain which is parallel to, and extends the length of, the ER/WR boundary. This westerly plunging domain (the WPD) transects both metasedimentary rocks of the ERS and metavolcanic rocks of the SLGB and is illustrated by the stippled pattern in Figure 12.4. A contrasting domain of easterly plunging (35° to 70°) lineations extends across the northern part of the ERS. South of the boundary, granitoid rocks of the WRS possess lineations that plunge moderately to steeply (45° to 75°) to the east and locally to the west. The attitudes of lineations in the WRS in part reflect primary fabrics of individual plutons.

FOLDS

Folds are commonly observed throughout the ERS, in the northern part of the SLGB and in metavolcanic remnants at the ER/WR boundary (Figure 12.4), but are rarely observed in the WRS. Metatexites of the ERS exhibit symmetric, tight to isoclinal folds that plunge moderately (30° to 60°) to the east and west. Asymmetric S–folds are also common and are restricted to the WPD. S–folds plunge westerly (40° to 70°) and their axes parallel the maximum extension direction in the WPD. Parallelism of S–fold axes and lineations in the WPD is attributed to clockwise rotation of initially east–plunging S–fold axes during shearing (*see* below). At the ER/WR boundary, linear zones of highly strained metavolcanic and metasedimentary rocks exhibit pervasive, westerly plunging (40° to 55°) asymmetric Z–folds. These zones trend easterly and coincide with discrete zones of right–handed strike–slip shear (Figures 12.4 and 12.5).

DEFORMATION ZONES AND SHEAR FRACTURES

Highly strained and mylonitized rocks occur in the vicinity of the ER/WR boundary (Figure 12.5). Two shear zone sets are distinguished by their relative ages. First–generation shear zones are up to 1 km wide, trend northeasterly (045° to 080°), dip steeply and transect the southern part of the WPD. Mineral lineations within these zones plunge steeply westward and parallel the maximum extension direction in the WPD. Kinematic indicators within these zones were rarely observed in the field; however, the asymmetry of folds in these deformation zones is predominantly S. Thus, steep westerly plunging lineations combined with S–folds on horizontal exposures suggest overall oblique, south–side–up, left–handed (sinistral) displacement on the first–generation shear zones. This sense of displacement will be investigated further in the laboratory with petrofabric evidence from oriented samples.

Narrow shear zones showing right–handed (dextral) strike–slip displacement occur at the ER/WR boundary and transect metasedimentary, metavolcanic, and plutonic rocks which are affected by earlier oblique shear. Dextral shear zones possess shallow, easterly plunging mineral lineations, moderately–plunging Z–folds, and shear bands showing dextral displacement. Pseudotachylite (1 mm to 20 cm wide) is commonly associated with dextral shear zones.

Steeply dipping, conjugate shear fractures are commonly observed throughout the southern part of the ERS (Figure 12.5). Shear fractures are localized ductile offsets that undergo brittle failure. They commonly occur as parallel, *en echelon* structures, between which intervening material is rotated counterclockwise relative to the shear sense (*see* inset, Figure 12.5). In general, shear fractures showing dextral offset trend easterly (080° to 110°) while equally well developed sinistral shear fractures trend northeasterly (030° to 060°).

The structural patterns described above characterize the ER/WR boundary throughout most of the study area. Notable features and local variations in these patterns are described briefly below.

Oak Lake Area

In the central part of the study area near Oak Lake (Figure 12.2), the S_1 fabric is rarely recognized. Instead, the prominent easterly S_2 is represented by both gneissosity, and a parallel, planar schistosity. This is the only area where gneissosity is subparallel to S_2. Fabrics here are typically very straight, and rarely openly buckled. Folds are generally absent. At one locality, northeasterly plunging, symmetric folds were observed where migmatitic layering trends northeasterly. This area may represent a "window" in which an older fabric is preserved, since the northeasterly trend of gneissosity here parallels the S_1 trend throughout the ERS. Except at this one locality, the very straight nature of the metatexite layering in the Oak Lake area suggests that the earlier fabric of these rocks may have undergone severe transposition to an easterly direction.

Shear zones were not observed in the vicinity of the ER/WR boundary in the Oak Lake area. Although the boundary is largely obscured by Oak Lake, a moderate degree of strain is uniformly observed as the boundary is approached, both from the north and the south. The ER/WR boundary may be an intrusive contact in this area.

Western Lac Seul Area

In this area an obliquity between S_1 and S_2 fabrics is most apparent (Figure 12.3). For instance, in the ERS, S_1 is 50° *counterclockwise* to S_2, while in the WRS, S_1 is 40° to 90° *clockwise* to S_2 (Figure 12.3). These relationships suggest the S_1 fabric in the ERS did not form under the same stress conditions as the S_1 fabric in the WRS, and provide evidence to suggest that early fabrics in these two subprovinces formed independently or were not coeval.

In the southwestern part of Lac Seul, folds are observed in the WRS in strongly foliated to gneissic tonalite. These folds are symmetric W-folds that plunge moderately to the east and northeast (Figure 12.4).

Shear fractures are not commonly observed in this area. Where observed, sinistral shear fractures trend northeasterly, which is consistent with the regional pattern. However, shear fractures showing dextral offset here trend northwesterly (Figure 12.5).

Eastern Lac Seul Area

The eastern part of Lac Seul is characterized by shallowly dipping planar fabrics, and shallowly plunging linear elements. In the ERS for instance, northeasterly trending gneissosity dips 10°E to 40°SE; and in the WRS, northerly and northwesterly trending gneissosity dips 15°W to 30°E. The overprinting, easterly trending S_2 schistosity in this area dips moderately (25°S to 50°S) in the ERS, and steeply (70°S to 85°S) in the WRS. The trend of S_2 here is notably oblique (15° counterclockwise) to the ER/WR boundary.

Lineations in the WPD plunge between 15°W and 25°W, which is much shallower than observed elsewhere along the boundary. North of the WPD, lineations plunge moderately to shallowly eastward at 10° to 50°. South of the ER/WR boundary, granitoid rocks of the WRS possess shallow (20° to 30°), easterly plunging mineral lineations.

In the eastern part of Lac Seul, dextral shear zones are not restricted to the ER/WR boundary. At two localities north of the ER/WR boundary (at 10 km and 40 km), easterly trending dextral strike–slip shear zones (40 cm wide) were observed.

In the eastern Lac Seul area, shear fractures displaying both sinistral and dextral displacement are observed. Sinistral shear fractures dominate and trend 080°, while dextral shear fractures trend 045° and 100° (Figure 12.5). These attitudes deviate from the orientation of shear fractures throughout the study area, where dextral shear fractures trend easterly, and conjugate sinistral shear fractures trend northeasterly.

DISCUSSION OF TECTONIC IMPLICATIONS

The regional structural patterns described above provide constraints concerning the tectonic history of the ERS and the WRS. For instance, contrasting trends of S_1 in the ERS (northeasterly) relative to the WRS (north to northwesterly), suggest that the earliest deformation event (D_1) recognized in these belts did not take place under similar stress conditions. This would imply either that these two belts were initially deformed independently (of one another), or that the earliest recognized event in each of these belts was not coeval.

In contrast, the prominent, easterly trending S_2 schistosity that transects both the ERS and parts of the WRS (particularly the SLGB), reveals that these belts were involved together in a second deformation event (D_2), the effects of which are most intense along the boundary between the ERS and the SLGB. The easterly striking fabric (S_2) generated during this event indicates that the D_2 event involved a component of north–south compression. Easterly plunging lineations on S_2 planes in the northern part of the ERS reveal that extension during D_2 compression was easterly. Westerly plunging lineations on S_2 planes straddling the boundary reveal that maximum extension in this area during D_2 plunged moderately to steeply westward. The pattern of lineations south of the WPD reveals that the D_2 event is not a product of pluton emplacement in the WRS, since the extension direction in granitoids of the WRS is variable, and rarely to the west.

First-generation shear zones adjacent to the ER/WR boundary possess westerly plunging lineations that parallel the lineations in the WPD. Parallel linear fabrics suggest the first-generation shear zones were initiated during the D_2 event. It would therefore appear that the D_2 event, in addition to north–south compression, involved oblique, south-side-up, sinistral shear (of the WRS relative to the ERS).

Overprinting relationships reveal that dextral strike–slip shear post-dated the D_2 event, and represents D_3. The distribution of dextral shear zones suggests that dextral shear affected the entire length of the ER/WR boundary, but was more localized than earlier D_2 shearing. Easterly plunging mineral lineations in dextral shear zones suggest that dextral shearing did not take place under the same stress conditions as D_2 shearing (where steep, westerly extension prevailed). Attitudes of conjugate shear fractures across the study area suggest that these structures developed during northwesterly directed transpression during D_3.

Variations in structural style in the eastern Lac Seul area may be the product of deformation related to the Miniss River Fault Zone (MRFZ), a major northeasterly trending, sinistral, strike–slip fault which lies roughly 40 km east of Lac Seul. Where the MRFZ cuts the ERS and the WRS, these belts are considerably more narrow and are displaced in a left–handed fashion. Consequently, the Savant Lake Greenstone Belt of the Wabigoon Subprovince is exposed to the east of the MRFZ, on strike with the ERS and WRS.

At this early stage of investigation, interpretations of the tectonic evolution of this part of the Superior Province are tentative. With this in mind, structural data from this area indicate the following:

1. Contrasting structural trends of S_1 in the ERS and the WRS suggest that these terranes were formed and initially deformed as separate blocks or belts; or that the earliest recognized event in each of these belts was not coeval.
2. The attitudes and widespread distribution of structures related to D_2 suggest the ERS and WRS were deformed together during a second deformation event which involved north–south compression and oblique shearing. Oblique, south–side–up shearing suggests overriding of the WRS eastward onto the ERS. The sinistral component of movement may reflect westward "squeezing" of metasedimentary rocks of the ERS due to impingement of the WRS from the south during regional north–south compression.
3. Relatively late–stage (D_3), subhorizontally directed, oblique convergence (transpression) from the northwest resulted in dextral strike–slip shear along the ER/WR boundary.

CONCLUSIONS

The boundary between the English River and the Winnipeg River subprovinces corresponds to a lithologic, structural, and local metamorphic discontinuity. Structural data along the boundary and from adjoining segments of the subprovinces record at least three regional deformation events which have implications regarding the tectonic evolution of this part of the Superior Province. Contrasting structural trends of D_1 suggest that the ERS and WRS evolved as separate belts which were deformed initially in different stress regimes, or that the earliest recognized event in each of these belts was not coeval. A second deformation event (D_2) affected the ERS and parts of the WRS, and involved north–south compression and oblique shearing. A preliminary interpretation of south–side–up, sinistral displacement on D_2 shear zones north of the ER/WR boundary suggests overriding of the WRS onto the ERS. Relatively late–stage (D_3) northwesterly directed transpression resulted in localized dextral strike–slip shearing at the boundary between the ERS and the WRS.

The transpressive tectonic regime recognized at the ER/WR boundary is indicative of a favourable structural setting for gold mineralization. In addition, metavolcanic units adjacent to the boundary show potential for base metal mineralization. Assay results and lithogeochemical analyses (of unaltered metavolcanics) should aid further assessment of the mineral potential of this area.

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13. Project Number 88–7. The Wabigoon–Winnipeg River Subprovince Boundary Problem

G.P. Beakhouse

Geologist, Precambrian Geology Section, Ontario Geological Survey, Toronto.

INTRODUCTION

Approximately one month was devoted to examination of some critical areas relevant to the boundary relationships between the Wabigoon Subprovince (WSP) and Winnipeg River Subprovince (WRSP). Most of this time was spent in the Sioux Lookout area (Figure 13.1). This study contributes to a better understanding of the stratigraphy, structure, and tectonic history of the Superior Province in northwestern Ontario. An understanding of the relationships between subprovinces is critical to achieving this goal. The aim of this summer's field work was to further test a working hypothesis for one subprovincial boundary as outlined below.

A second objective was to evaluate the metallogeny of the subprovince boundary area. Several major faults have been interpreted to occur along lithological contacts in the Sioux Lookout area (Johnston 1972) and gold and sulphide mineralization occurs along some of these contacts. Disseminated Mo–Cu mineralization occurs in stocks southwest of the Sioux Lookout area and rare metal pegmatite deposits in the Dryden area occur in rocks correlative with those in the Sioux Lookout area.

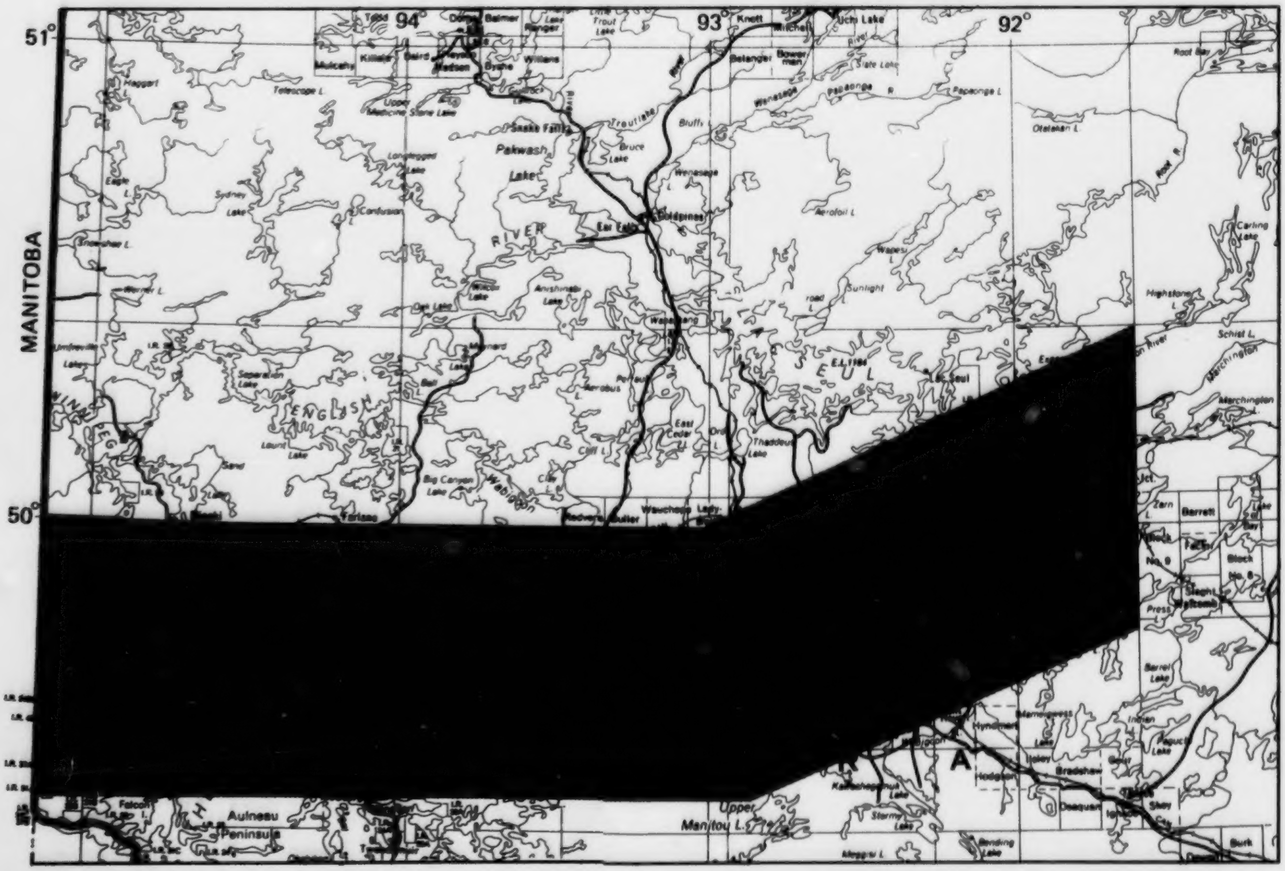
51°
50°
94°
93°
92°
MANITOBA
RIVER
ENGLISH
LAC SEUL
Pakwash Lake
Aulneau Peninsula
Upper Manitou L.
Carling Lake
Highstone L.
Schist L.
Marchington
Sydney Lake
Telescope L.
Red Lake

Figure 13.1. *Location map for the Sioux Lookout area. Scale: 1:1 584 000 or 1 inch to 25 miles.*

WABIGOON–WINNIPEG RIVER SUBPROVINCE RELATIONSHIPS—A WORKING HYPOTHESIS

The WSP and WRSP contrast sharply with respect to lithologies, structural style, age, and origin. The WSP consists of predominantly low metamorphic grade, bimodal (mafic and intermediate/felsic) volcanic sequences that face away from elliptical to amoeboid granitoid complexes that are coeval with at least some of these volcanic rocks (Blackburn *et al.* 1985; Thurston *et al.* 1985). Available U–Pb geochronology indicates that these rocks were erupted and intruded between 2775 and 2700 Ma (Davis *et al.* 1982; Davis and Edwards 1986). There is no evidence either from the geochemical characteristics of plutonic rocks (Beakhouse and McNutt 1985) or presence of inherited zircons (Davis and Edwards 1986) to suggest that older sialic crust was involved in the generation of these rocks.

In contrast, the WRSP consists mainly of plutonic and metaplutonic rocks. The metaplutonic rocks are significantly older (2830 to 3170 Ma, Krogh *et al.* 1976; Beakhouse 1983; Corfu 1988; Davis *et al.* 1988) than WSP volcanism. The late plutonic rocks of the WRSP are generally younger than WSP volcanism (2700 to 2660 Ma), but have geochemical and isotopic signatures that indicate they were derived by partial melting of the older metaplutonic rocks (Beakhouse 1983; Beakhouse and McNutt 1986). There is a notable paucity of igneous activity in the WRSP at the time of widespread volcanic and plutonic activity in the WSP. Taken together, these data suggest that the WRSP existed as an independent block of sialic crust prior to widespread igneous activity in the western Wabigoon Subprovince (Beakhouse 1985).

These and other lines of evidence have led several authors to conclude that the WSP is an ensimatic volcanic arc that developed independently of an older sialic terrane (WRSP) until approximately 2700 to 2710 Ma when they were coupled in an arc–continent collision (Blackburn 1980; Beakhouse and McNutt 1986; Davis *et al.* 1988). An area referred to herein as the Sioux Lookout terrane is interpreted to be the collision zone within which elements of the WSP, WRSP, and intervening ocean or back–arc basin were juxtaposed and deformed by thrusting, transcurrent faulting, and buckling. The generalized extent of this terrane is portrayed in Figure 13.2, although certain elements that define the terrane may extend beyond the bounds shown on the figure.

SIOUX LOOKOUT AREA

In the Sioux Lookout area, a sequence of alternating predominantly volcanic and predominantly sedimentary lithostratigraphic units, that are typically 3000 to 6000 m thick can be traced laterally for many tens of kilometres (Figure 13.2). All of the supracrustal rocks in the area have undergone low grade regional metamorphism and the prefix "meta" is omitted in the subsequent discussion. The major units illustrated in Figures 13.2 and 13.3 are briefly described below.

NORTHERN METAPLUTONIC COMPLEX

This unit consists of strongly deformed, metaplutonic rocks that occur within the WRSP. Tonalitic and leucotonalitic compositions predominate with lesser amounts of granodioritic, granitic, and gabbroic phases being widespread and locally abundant. These gneisses are intruded by mafic dikes which crosscut some of the gneissic fabric, but are strongly transposed into the orientation of the regional gneissic fabric and are themselves locally gneissic.

NORTHERN VOLCANIC BELT

This sequence is a southeast–younging homoclinal succession of massive and pillowed basalt flows and associated gabbro sills together with minor chert and magnetite ironstone and rare carbonate interflow sedimentary rocks. Several thin (less than 10 cm) beds of quartz arenite, occurring together with carbonate and chert–magnetite ironstone in a thin interflow sedimentary horizon, were identified in one outcrop near the base of this sequence. The intensity of deformation as estimated from the degree of flattening of pillows and intensity and pervasiveness of fabric development decreases gradually from the base of the sequence toward the top. Near the base of the sequence, pillows are deformed with typical axial ratios of 10:4:1 with the maximum axis oriented down the dip of the foliation. In the upper third of the sequence, strain is very low with common preservation of delicate primary structures and very weak fabric development. In the middle third of the sequence, strain is locally strong, though not as intense as that characterizing the base of the sequence, and deformation is heterogeneously distributed with the greatest strain and fabric intensity occurring within pillow breccia, hyaloclastite, and interflow sedimentary units.

NORTHERN SEDIMENTARY BELT

The northern sedimentary belt is a southeast–facing homoclinal succession that includes a basal, mixed sedimentary and volcanic sequence (the Patara sediments, Pettijohn 1935), overlain by a predominantly sedimentary sequence (the Abram Group). The Abram Group is further subdivided, in ascending stratigraphic order, into the Ament Bay, Daredevil, and Little Vermilion formations (Turner and Walker 1973).

The Patara sedimentary rocks and associated volcanic rocks overlie the northern volcanic belt. Although the contact was not observed, the absence of appreciable strain or fabric development within a

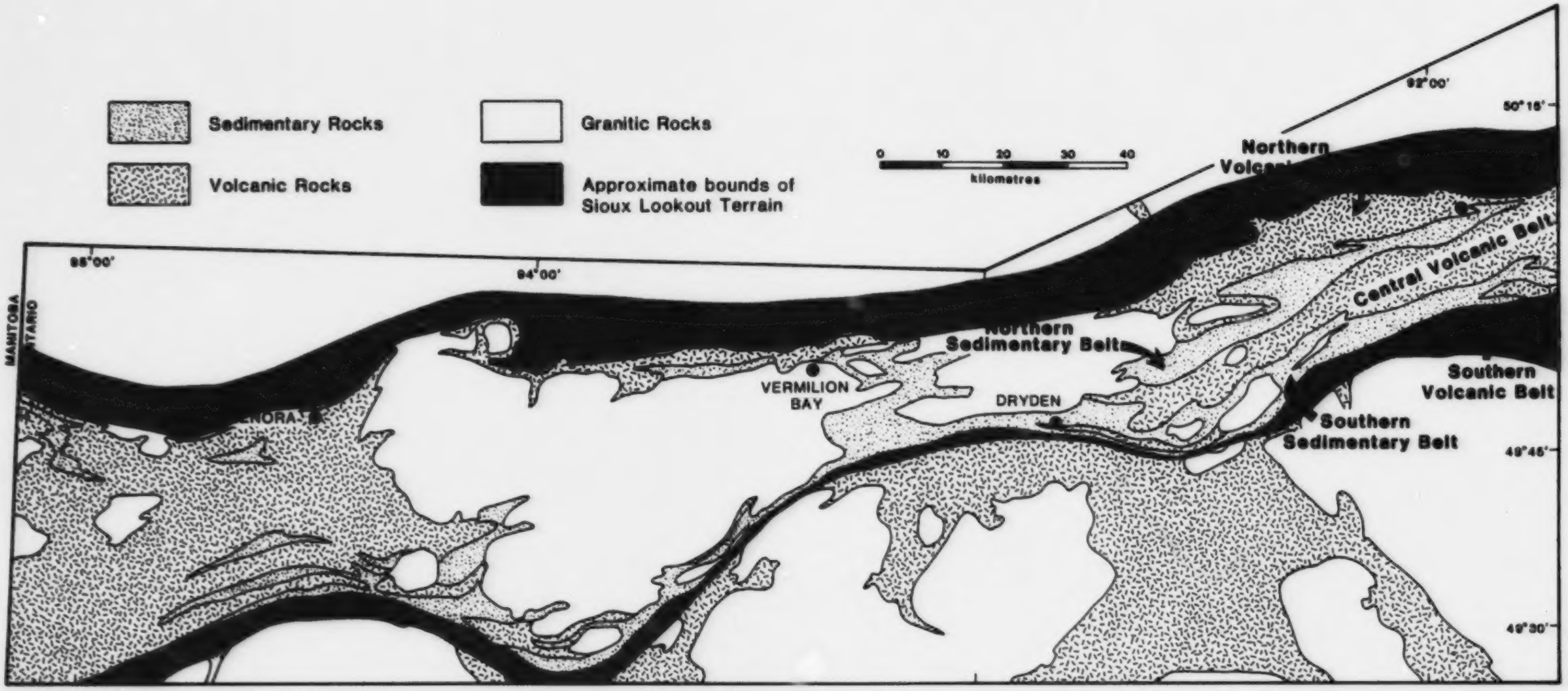
Sedimentary Rocks
Volcanic Rocks
Granitic Rocks
Approximate bounds of Sioux Lookout Terrain
0
10
20
30
40
kilometres
95°00'
94°00'
92°00'
50°15'
49°45'
49°30'
MANITOBA
ONTARIO
KENORA
VERMILION BAY
DRYDEN
Northern Volcanic Belt
Central Volcanic Belt
Northern Sedimentary Belt
Southern Volcanic Belt
Southern Sedimentary Belt

Figure 13.2. *Regional geological map of a part of the western Superior Province illustrating the possible extent of the Sioux Lookout terrane. The map is compiled from numerous published Ontario Geological Survey maps with additional unpublished information from the Lake of the Woods area (G.W. Johns, Geologist, Ontario Geological Survey, Toronto, personal communication, 1988). The boundary is drawn as a shaded area to emphasize both the preliminary nature of the definition of this terrane and the likelihood that the terrane is not sharply bounded.*

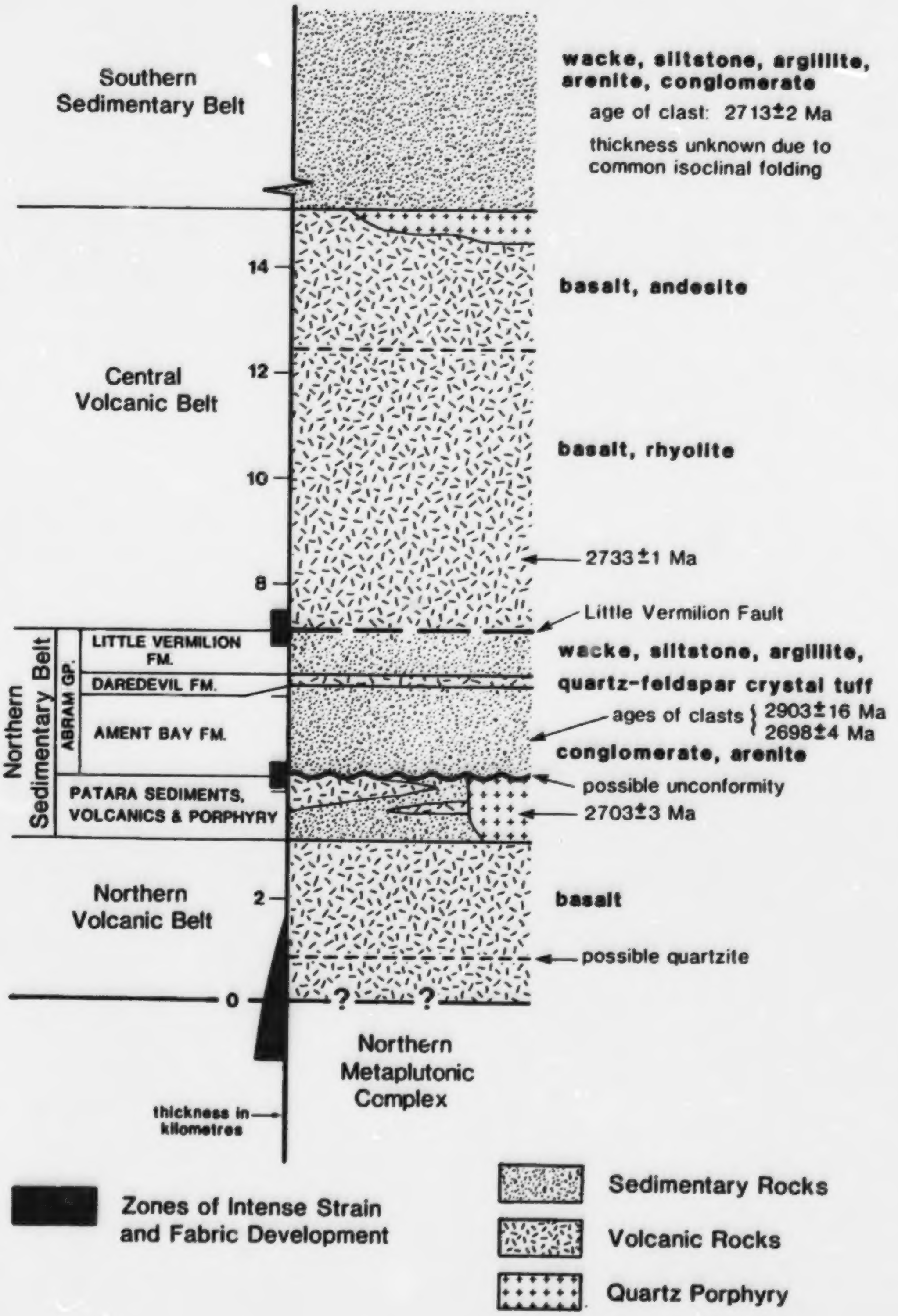
Southern Sedimentary Belt
wacke, siltstone, argillite, arenite, conglomerate
age of clast: 2713±2 Ma
thickness unknown due to common isoclinal folding
14
12
10
8
2
0
Central Volcanic Belt
basalt, andesite
basalt, rhyolite
2733±1 Ma
Little Vermilion Fault
Northern Sedimentary Belt
ABRAM GP.
LITTLE VERMILION FM.
DAREDEVIL FM.
AMENT BAY FM.
PATARA SEDIMENTS, VOLCANICS & PORPHYRY
wacke, siltstone, argillite,
quartz-feldspar crystal tuff
ages of clasts 2903±16 Ma 2698±4 Ma
conglomerate, arenite
possible unconformity
2703±3 Ma
Northern Volcanic Belt
basalt
possible quartzite
?
?
Northern Metaplutonic Complex
thickness in kilometres
Zones of Intense Strain and Fabric Development
Sedimentary Rocks
Volcanic Rocks
Quartz Porphyry

Figure 13.3. *Stratigraphic column for the Sioux Lookout area (modified from Turner and Walker 1973). U-Pb ages quoted in the figure are from Davis and Trowell (1982) and Davis et al. (1988).*

few metres of the contact suggests that no fault is present. The Patara sedimentary rocks exhibit a general fining upward trend that is well displayed in exposures along Highway 116. Here, the basal unit is a clast–supported, oligomictic conglomerate that exhibits little internal stratification and is composed of poorly sorted, subangular to subrounded mafic volcanic clasts within a mafic matrix. Rarely, the fragments are recognizable as pillow fragments partly bounded by selvage material. This unit pinches out along strike and grades upward into similar conglomerates that are interbedded with sandstones, which are in turn succeeded by sandstone without coarse fragmental interbeds and, finally, fine–grained sandstone and argillite. This sequence is interpreted to represent a slope–wash deposit on top of the northern volcanic belt mafic plain or shield volcano. Topographic depressions infilled with locally derived mafic breccia created a more uniformly gently dipping depositional surface upon which progressively finer debris derived from the erosion of the mafic shield could be deposited.

The Patara sedimentary rocks are locally overlain by felsic volcanic rocks and perhaps by mafic volcanic rocks, although intense deformation at the contacts of the latter on Vermilion Lake make it difficult to rule out the possibility that the Patara sedimentary rocks are not tectonically juxtaposed with these rocks. A unit described as a quartz porphyry (Johnston 1972), that has been critical in deciphering regional stratigraphic relationships, also occurs at the top of the Patara sedimentary rocks. The unit has a U–Pb zircon age of 2703±3 Ma (Davis *et al.* 1988). The porphyry is strongly deformed and most of the contacts are either strongly tectonized or beneath the waters of Vermilion Lake. Most workers have regarded the unit as having an intrusive origin (Johnston 1972; Turner and Walker 1973; Davis *et al.* 1988), but in the absence of clear intrusive relationships and diagnostic textural evidence, it is equally probable that the unit represents a felsic dome that may be related to felsic metavolcanic rocks that occur elsewhere at this stratigraphic level.

The Abram Group has been interpreted to unconformably overlie the Patara sedimentary rocks, associated volcanic rocks, and the porphyry described above largely on the basis of a profound and abrupt change in the provenance of the sedimentary rocks (Turner and Walker 1973). The Patara sediments have a predominantly volcanic provenance, whereas the abundance of granitoid boulders and the higher quartz content of the sandstones in the Abram Group indicates a significant granitoid provenance component. Turner and Walker (1973) favoured the interpretation that the granitoid component originated from plutons that intruded and uplifted the volcanic sequence and that significant erosion preceded deposition of the Abram Group but acknowledged the possibility that the source of the detritus could have been prevolcanic sialic crust. Examination of the clast population within the Abram Group reveals many similarities with the Winnipeg River terrane which lies to the north of, and is interpreted to be significantly older than, any known volcanism in the Wabigoon Subprovince. This is consistent with a U–Pb zircon age of 2903±16 Ma for a tonalite clast from the Abram Group (Davis *et al.* 1988).

Much of the northern sedimentary belt is characterized by low strain and very weak fabric development. Exceptions to this generalization include the Patara–Abram contact and the Abram–central volcanic belt contact where zones that are typically less than 100 m wide have been intensely strained. Both of these contacts have been inferred to be faults (Johnston 1972).

CENTRAL VOLCANIC BELT

The central volcanic belt is a predominantly southeast–facing sequence of mafic to felsic volcanic rocks. The base of this sequence is interpreted to be in fault contact with the underlying northern sedimentary belt (Johnston 1972). South of Sioux Lookout, this sequence has been interpreted to consist of a lower, bimodal tholeiitic basalt + subordinate dacite/rhyolite interval succeeded by a mixed basalt–andesite interval (Page and Clifford 1977; Page *et al.* 1978). A generally similar subdivision of the central volcanic belt has also been recognized in the Beartrack Lake area located approximately 40 km southwest of Sioux Lookout (Berger 1987; Chorlton 1987). A felsic tuff from the lower part of the central volcanic belt has a U–Pb zircon age of 2733±1 Ma (Davis and Trowell 1982).

Limited observations made in this belt are consistent with these generalizations and suggest an overall low degree of strain except near the basal contact with the Abram Group. A distinctive porphyry unit occuring near the stratigraphic top of this belt is similar to that occurring beneath the Abram Group.

SOUTHERN SEDIMENTARY BELT

Exposures of this belt in East Bay of Minnitaki Lake consist exclusively of sedimentary rocks. To the southwest in the same belt, subordinate felsic volcanic rocks are interlayered with the sedimentary rocks (Berger 1986). Unlike the three belts described above, this belt is deformed into numerous shallowly plunging, upright isoclinal folds. Nevertheless, these rocks appear to overlie the central volcanic belt and the general southeastward facing of the regional stratigraphy described above persists into the southern sedimentary belt. Rock types encountered within this belt during this field work include wacke, siltstone, argillite, arenite, and conglomerate. The distinctive foliated to gneissic tonalite and megacrystic granodiorite clasts of the Abram Group conglomerates that are interpreted to be derived from the WRSP are lacking in the conglomerates of the southern volcanic belt. Here, the sediments appear to be derived primarily from greenstone lithologies and related subvolcanic intrusive rocks.

SOUTHERN VOLCANIC BELT

This belt was not examined. Previous work suggests it is a mafic volcanic sequence with subordinate intermediate to felsic volcanic rocks and a minor sedimentary component and lacks a consistent facing direction (Trowell *et al.* 1980a, 1980b). The contact between the southern volcanic and southern sedimentary belts has been interpreted to be a fault (Johnston 1972). The stratigraphic position of this belt relative to those discussed above and its possible inclusion in the Sioux Lookout terrane remain uncertain.

INTERRELATIONSHIPS OF STRATIGRAPHY, STRUCTURE, AND ALTERATION IN THE NORTHERN VOLCANIC BELT

The recognition of a strain gradient within the stratigraphically and lithologically monotonous northern volcanic belt permitted some observations relevant to the potential relationships between stratigraphy and various deformational and alteration features. Within the weakly to very weakly deformed part of this sequence, it is possible to recognize lithologic dissimilarities between relatively undeformed zones (gabbro, massive and pillowed flows) and those exhibiting a greater degree of strain and intensity of fabric development (interflow sedimentary rocks, hyaloclastite, and pillow breccia). Furthermore, these more highly strained units are loci for quartz veining and carbonate alteration. With greater amounts of strain and alteration, many of the primary structures and textures that identify the origin of these zones are obliterated. In many outcrops, chert and recrystallized quartz veins are distinguished with difficulty and at one locality a pure, milky quartz vein was observed to grade laterally into a laminated chert–magnetite bed. Based on the progressive changes described above, the occasional incorporation of distinctive compositions (eg. magnetite ironstone) and similarities in spacing of structures, it is concluded that many of the more highly strained and altered zones occurring within the basal part of the northern volcanic belt also originated as stratigraphic units.

METALLOGENY OF THE SIOUX LOOKOUT TERRANE

A preliminary review of the types and distribution of mineral occurrences (Ferguson *et al.* 1970; Breaks 1979; Blackburn 1981) within the Sioux Lookout terrane suggests that it is characterized by a distinctive metallogeny. Types of mineralization present include:

1. Au – These deposits are hosted in a wide variety of rock types and many are spatially related to faults.
2. Base–metal sulphide mineralization – Cu and/or Zn dominated sulphide mineralization are predominantly volcanic hosted.
3. Rare Metal Pegmatites – These deposits which are enriched in Li, Ta, Nb, Cs, and Be are associated with pegmatites occurring within mafic volcanic rocks near the margins of granitoid intrusions (Breaks and Kuehner 1984).
4. Uranium mineralization occurs within two genetic types of pegmatites that originated from the partial melting of sedimentary rocks and the fractionation of potassic granitic plutons (Breaks 1982).
5. Molybdenum, with or without associated Cu and Au mineralization, is associated with granitic stocks.

In comparison to that part of the WSP lying to the south of the Sioux Lookout terrane, types 1 and 2 appear to occur in both terranes, types 3 and 4 are restricted to the Sioux Lookout terrane, and type 5 occurs in both but may be more common in the Sioux Lookout terrane.

IMPLICATIONS

Some preliminary conclusions concerning the significance of observations from the Sioux Lookout area for the working hypothesis outlined above are:

1. The northern volcanic and sedimentary belts record a transition from volcanism to volcaniclastic sedimentation to epiclastic sedimentation. Older continental crust contributed detritus to the Abram Group, and the presence of quartz arenite near the base of the northern volcanic belt suggests that older granitoid units may have been adjacent to this sequence throughout its development.
2. The central volcanic belt and southern sedimentary belt similarly record a volcanic to sedimentary transition; however, detritus appears to have been derived from the volcanic rocks and related subvolcanic intrusions with no evidence for a significant contribution from older sial.
3. The stratigraphic asymmetry, distribution of strain, and evidence of older rocks overlying younger rocks suggests that the Sioux Lookout terrane represents an imbricate thrust stack.
4. The nature and diversity of lithologies suggests that the sequences in the Sioux Lookout terrane are more closely analogous to island arcs or back–arc basins than oceanic crust, although the northern volcanic belt may have some attributes of the latter.

5. The Sioux Lookout terrane contains Au and base-metal deposits similar to those occurring elsewhere in the WSP, but U and rare metal pegmatite mineralization is peculiar to the Sioux Lookout terrane.

SUMMARY

Observations and interpretations discussed above suggest that an area referred to informally as the Sioux Lookout terrane is composed of allochthonous volcanic/sedimentary sequences, the emplacement of which is related to the interaction between the WRSP and WSP. The allochthonous terrane includes areas that have hitherto been included in both subprovinces and points to the need to rethink the concept and definition of subprovinces and their boundaries. These relationships and interpretations suggest that, in this case, the concept of a sharp, discrete subprovince boundary should be abandoned in favour of the concept of a boundary terrane.

The Sioux Lookout terrane may be metallogenically distinct from the remainder of the WSP. In addition to gold and base-metal mineralization, there is also potential for the discovery of uraniferous and rare element pegmatites

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14. Project Number 87–17. Preliminary Investigations of the Structure of the Slate Lake Area, Uchi Subprovince

H.R. Williams

Geologist, Precambrian Geology Section, Ontario Geological Survey, Toronto.

INTRODUCTION

The Slate Lake area was recently mapped at a scale of 1:15 840 (Bowen 1984). The re–investigation reported here is prompted by the need for the local stratigraphy and mineral potential to be placed within the constraints of a structural framework. In addition, the area is marginal to a little known portion of the boundary between the Uchi and English River subprovinces. Elsewhere in the Superior Province these boundaries are known to display enhanced mineral potential.

The three week field project took advantage of vastly improved access; critical exposures are now more readily available than when Bowen mapped the area in 1980. Great Lakes Forest Management roads now allow year–round access to Slate, Badrock, Ben, Papaonga, and Whitemud lakes and their environs. Re–examination of exposures found by Bowen and examination of many new roadside outcrops in the study area (Figure 14.1) was undertaken to determine the structural style and whether the stratigraphic succession is original or is repeated by folding or thrusting.

The reader is referred to Bowen (1984) for a review of the stratigraphy of the area which consists of an apparently repetitive succession of mafic, intermediate, and felsic volcanics, derived sediments, conglomerates, and ironstones, intruded by granitoids. Alteration of these rocks, especially the volcanics and sediments, has produced rocks rich in aluminous minerals such as andalusite and garnet.

The Slate Lake area has come under close scrutiny for three reasons. Lithotectonic patterns in the area appear to be similar to those in the eastern end of the Beardmore–Geraldton Belt and the northern part of the Wawa Subprovince north of Terrace Bay (Devaney and Williams, in press; Williams 1986, 1987a, b). The stratigraphic succession is complex with marked changes in local younging directions that are difficult to explain by inclined folding alone. Exploration interest in the area encourages extension southwards of the structural work carried out by

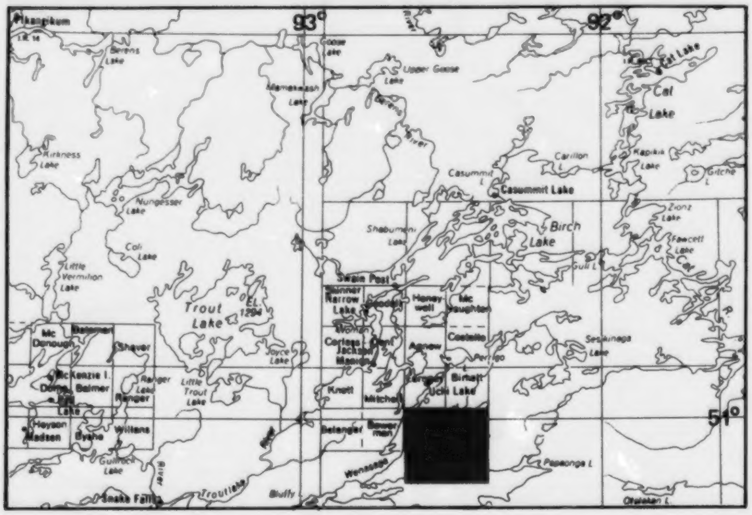
Pikangikum
93°
92°
51°
Berens Lake
Mamakwash Lake
Upper Goose Lake
Berens River
Kirkness Lake
Nungesser Lake
Casummit L
Casummit Lake
Carillon L
Kapikik Lake
Gitche L
Cat Lake
Cat Lake
Col Lake
Little Vermilion Lake
Shabumeni Lake
Birch Lake
Zionz Lake
Fawcett Lake
Gull L
Trout Lake
EL. 1294
Swain Post
Skinner
Narrow Lake
Honeywell
McNaughton
Costello
Agnew
Perrigo
Birkett
Uchi Lake
Seseikinaga Lake
Mc Donough
Shaver
McKenzie I.
Balmer
Ranger Lake
Ranger
Little Trout Lake
Joyce Lake
Knott
Mitchell
Heyson
Madsen
Bysshe
Willans
Belanger
Bowerman
Gullrock Lake
Snake Falls
Trout Lake
Bluffy
Wenasaga
Papaonga L
Otatakan L

Figure 14.1. *Location map for the Slate Lake area, Uchi Subprovince. Scale: 1:1 584 000 or 1 inch to 25 miles.*

CANADA ONTARIO

This project A.5.3 is part of the five year Canada–Ontario 1985 Mineral Development Agreement (COMDA), a subsidiary agreement to the Economic and Regional Development Agreement (ERDA) signed by the governments of Canada and Ontario.

Fyon and Lane (1986) in the Uchi–Confederation–Woman lakes area. The following is a résumé of the investigations of the domainal structure, contact relationships, fabric development, and stratigraphic ordering within the belt. This information provides a regional structural perspective for exploration projects.

STRUCTURAL DOMAINS

The two structural domains defined by Fyon and Lane (1986) in the Uchi–Confederation–Woman lakes area have also been recognized in the Slate Lake study area, along with a third domain which corresponds to the migmatitic metasediments of the English River Subprovince.

Domain I is characterized by steeply dipping to vertical planar fabrics which are decorated by a moderately southwest to vertically plunging mineral lineation and stretching fabric. Folds, usually confined to strongly anisotropic lithologies such as cherty ironstones and clastic metasediments or altered material containing quartz veining, have steep plunges and are tight to isoclinal in form with axial surfaces generally parallel with the dominant planar fabric. Locally, towards the Uchi–English River Subprovince boundary, these minor structures have been overprinted by structures characteristic of Domain II and by a subsequent, static, thermally induced, metamorphic recrystallization producing garbenschiefer texture.

Domain II is also characterized by steep to vertical planar fabrics, but these are decorated by moderately southwest–plunging to subhorizontal mineral lineations and fold axes. Development of these structures is by rotation and intensification of the structures produced and preserved in Domain I and the development of entirely new fabrics. Without exception, Domain II fabrics indicate a process of dextral, ductile, simple shear along nearly vertical, east–northeasterly oriented surfaces. The sense of motion across these surfaces is indicated by numerous, asymmetric, Z–style folds; extensional crenulation fabrics; asymmetric boudinage and discrete vein displacement. In the most deformed portions of Domain II, near the trace of the Lake St. Joseph–Sydney Lake Fault Zone, all primary sedimentary structures are replaced by those typical of mylonites, such as loss of lithological continuity, the occurrence of listric structures nearly parallel with layering, intense fabric development, alteration and veining. Massive granitoid rocks such as the West Badrock Lake Pluton are affected only by brittle shear zones, chloritic veining and pseudotachylytes in this domain. Domain II structures occur within the southern portion of the area, spatially associated with the subprovincial boundary, but are also found within areas of especially deformable rock such as ironstone–bearing sequences within Domain I. Domain II links the previously separate Lake St. Joseph and Sydney Lake deformation zones as one continuous, dextral–sense structure.

Domain III occurs south of the major shear zone that produced Domain II structures. In this domain, migmatitic metasediments and attendant granitoids, such as the Bluffy Lake and Papaonga plutons, characteristically exhibit sinistral sense of motion indicators and a moderate to steeply east–plunging lineation on vertical to south–dipping foliations. Imbricate structures developed during deformation indicate a sinistral sense of shear when viewed on horizontal surfaces, but the dominant sense of shear is probably steeply plunging and south side down.

Whilst the relative timing of structure development within Domains I and II is clear, the original orientation of Domain I structures prior to the imposition of Domain II structures is unknown; progressive steepening of originally flat–lying structures may be a characteristic of Domain I, or a period of upright folding may have separated the development of the two domains. The timing of Domain III is unclear, but it probably pre–dates Domain II since similar structures examined by Sanborn–Barrie (this volume) within the English River Subprovince at Separation Lake, some 100 km southwest of Slate Lake, are clearly cross–cut by Domain II dextral–sense structures.

An understanding of the geometry and development of the structures contained within the contrasting domains is necessary to predict the distribution and three dimensional shape of mineralized zones. It is likely that individual ore bodies are elongate along the stretching fabric. Some zones of high shear strain are coincident with alteration and veining.

CONTACT RELATIONSHIPS BETWEEN UNITS

Contacts between lithological units were rarely observed except in Slate Lake itself where exposures of boundaries between volcanics and sediments of various types were examined and found to be zones of high strain, sometimes with carbonate alteration and quartz veining. Contacts exhibit strongly developed schistosity and an associated, steeply plunging linear fabric.

In no case was an intact conformable boundary recognized; one result of this observation is that a continuous stratigraphic sequence in the area cannot reasonably be assumed. The ramifications of this statement are considerable. Unexpected lithologies within a stratigraphic sequence or repetition of units may both be a consequence of near layer–parallel shearing.

FABRIC DEVELOPMENT

Domain I fabrics consist of original stratification (or its transposed equivalent in zones of high strain) that is locally deformed into folds, with a corresponding development of an axial planar fabric. An earlier phase of folding, locally seen as isoclinal, intrafolial folding of bedding, appears as rare precursors to Domain I folding and causes Domain I folds to exhibit both northeast and southwest structural facing directions. Domain I folds are steeply plunging in the north, becoming tighter southwards; this general intensification of Domain I folds and a general shallowing of lineation plunge southwards may in part be due to Domain II reworking and in part to regional variation.

Domain II structures usually refold Domain I structures and fabrics. Where Domain I and II folds are coaxial, which is the case in the central part of the area, separating the two phases is difficult because the flattening fabrics forming as a result of the Domain II dextral shear system are parallel to the general Domain I fabric orientation. Further south, near the main focus of the dextral deformation around the Papaonga–Whitemud lakes system, Domain I fabrics are rotated into the main easterly shearing direction so that Domain II flattening fabrics such as Z–style folds and associated axial planar cleavage can be seen crossing the earlier Domain I fabrics. Domain II planar fabrics are usually vertical and contain a variety of steep to shallow to subhorizontal lineations, depending on the intensity of shearing, the lithology and the rotation of Domain I structures.

Too little is known of Domain III fabrics to be able to assess their timing and mode of production. Intense shearing along layer surfaces is clear from both the production of sheath–folded veins and sinistral–sense imbrication of sections of the stratigraphy after the production of the dominant foliation.

Fabric development in zones of high strain and at lithological contacts is not solely responsible for alteration patterns in the area; lithological control of alteration to aluminous mineral assemblages is associated with the distribution of felsic and mafic metavolcanic rocks. It is clear, however, that these altered rocks are susceptible to subsequent deformation processes.

STRATIGRAPHIC ORDERING

Rather few of the way–up indicators recorded for specific localities by previous mappers could be substantiated. Recognition of pervasive planar deformation fabrics and associated folding and of a high strain state, especially within metasediments, was not fully appreciated previously. The use of deformed pillows in mafic volcanics and grain size gradation in wackes and volcanics was found to be equivocal, considering the new planar fabrics imprinted upon the primary features. Indeed, in many of the rocks within Slate Lake itself, few primary features were recognized. The concept of a system of southwest oriented, moderately plunging folds (Bowen 1984, p.60) to explain the sequence and repetition of the regional–scale stratigraphy was not substantiated; indeed, using symmetry principles, the structural development of the area must result from at least two deformations. The near vertical orientation of some fold axes and lack of consistent stratigraphic facing indicators suggest that structural geometry is exceedingly complex within mappable stratigraphic units such as wackes. Considering the strike length of the belt to be approximately 30 km as a minimum and the lack of stratigraphic continuity along the belt, use of a single phase of vertically or steeply plunging folds to explain the regional stratigraphic ordering of this belt is unwise. Folds could, however, develop on this scale with a recumbent orientation and then undergo reoriention towards vertical during intense shear. Evidence of this strong deformation is best displayed in Slate Lake itself. There, sheath fold–generated minor structures, high intensity of erect planar and linear fabric development, and a focussing of alteration effects, occur within a narrow zone of deformation herein defined as the Slate Lake Deformation Zone.

The stratigraphy of the area is in a highly tectonized state. Deformation within lithological units and the recognition of high strains at their mutual contacts suggest that these rocks do not exhibit original relationships or sequences. This statement should not be seen as discouragement, but as a call for thoughtful interpretation of these complex rocks.

DISCUSSION

This short project has demonstrated that the Slate Lake area contains both mildly and highly tectonized rocks that can be separated into domains of characteristic structure. An unbroken stratigraphic sequence within domains is unlikely; repetition may be tectonically induced by both folding and thrusting.

ACKNOWLEDGMENTS

Constructive criticism and technical assistance by M. Dolan are appreciated.

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15. Project Number 88–33. Stratigraphy and Structure of Archean Metasediments and Metavolcanics in the Thompson and James Bay Areas (Pipestone Lake), Wabigoon Subprovince

G.R. Edwards and M.R. Stauffer

Geological Sciences, University of Saskatchewan, Saskatoon.

INTRODUCTION

This report describes Archean metavolcanic and metasedimentary rocks in a 25 km^2 area at Thompson Bay and James Bay (Pipestone Lake), northwestern Ontario (Figure 15.1). Previous field work by G.R. Edwards (1983a, b) and co-workers provide the base for this work but earlier mapping was also done by J.E. Thomson (1935, 1936), A.C. Lawson (1889) and A.P. Coleman (1895, 1897). Regional geological relationships were synthesized by A.M. Goodwin (1965) and compiled by C.E. Blackburn on the Kenora–Fort Frances Compilation Map 2443, published in 1979. The prefix 'meta' is not used in this report; rocks in the area are, however, metamorphosed to low greenschist facies assemblages.

The object of the field work is to examine in detail structural–stratigraphic discordances identified by Edwards (1983a) in the James and Thompson Bay areas. We seek to establish evidence for the character of early folding and possible presence of unconformities in the greenstone sequence. To study this discordance, several pertinent contacts were stripped and examined for evidence of unconformity or faulting. As much as possible, the structural geometry of the Thompson Bay sediments was analyzed.

GENERAL GEOLOGY

The Thompson and James Bay areas lie between the Wabigoon Diapiric Axis to the south (Edwards and Sutcliffe 1980), and the Manitou Stretch–Pipestone Lake shear zone (MPSZ, Figure 15.2) to the north. A detailed lithologic description of the Thompson and James Bay areas is given by Edwards (1983a, b), who mapped the general area of Pipestone and Straw lakes at a scale of 1:15 840. New structural and stratigraphic information obtained from the current field work are discussed below.

Edwards (1983a) found no way-up indicators in the basaltic–andesitic fragmental rocks (BAF) near enough to Thompson Bay to be of use in relating BAF to the Thompson Bay sediments (TBS) or pil-

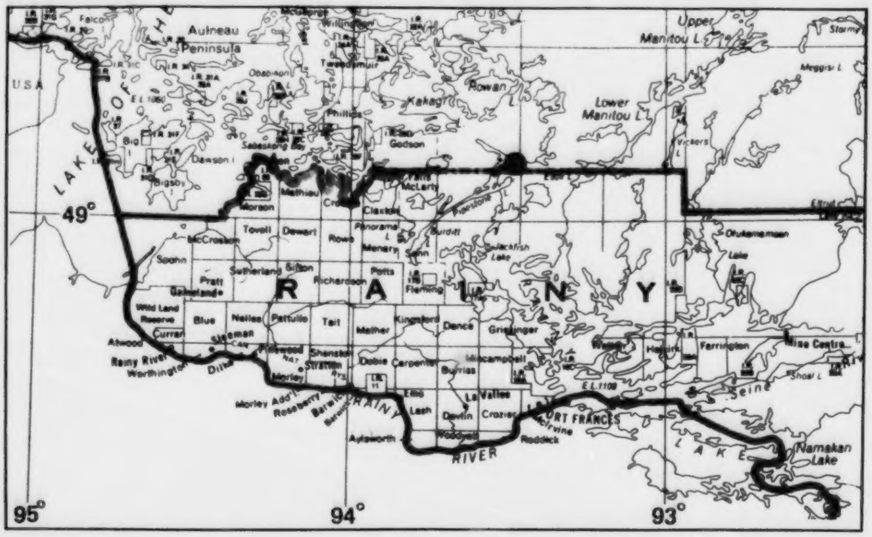

Figure 15.1. *Location map for the Pipestone Lake Area. Scale: 1:1 584 000 or 1 inch to 25 miles.*

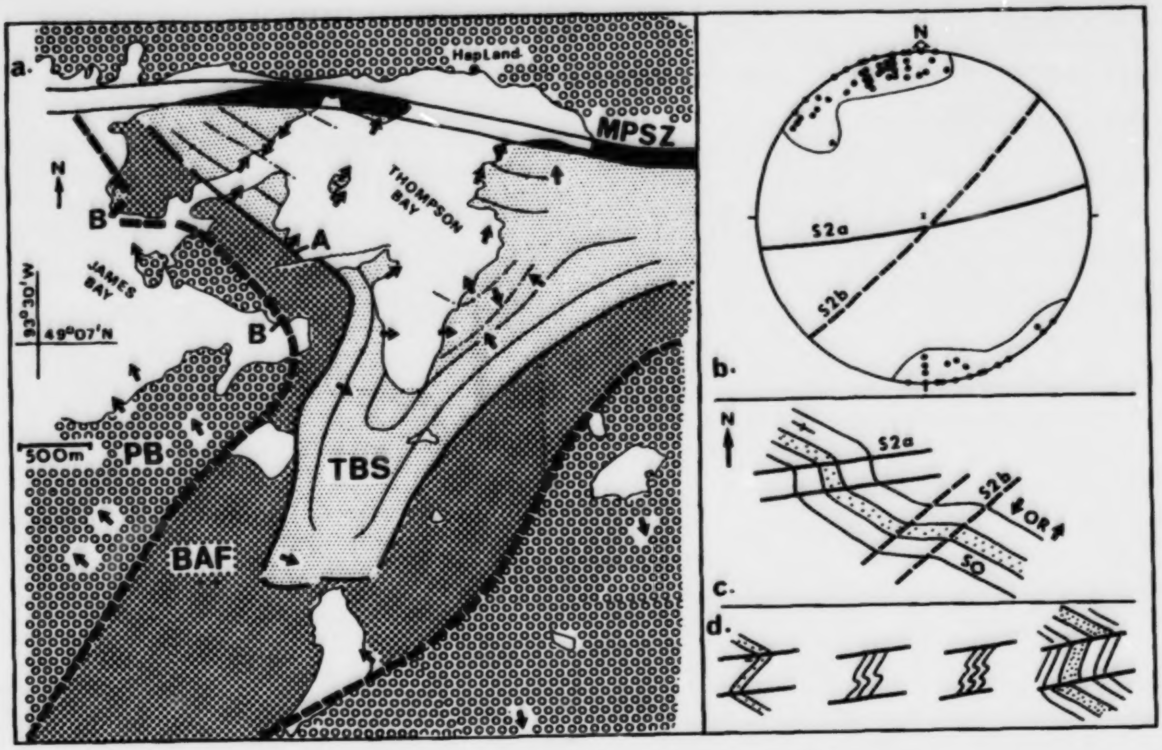

Figure 15.2a. *Geological map of the Thompson Bay-James Bay portion of Pipestone Lake (modified from Edwards 1983a). Open circles—pillowed and massive basalt (PB). Squares—mainly fragmental basalt to andesite (BAF). Small dots—sedimentary rock (TBS). Large stubby arrows show stratigraphic facing. Heavy dashed line between PB and BAF shows a major contact of unknown origin. Bedding trends in sedimentary rocks are shown by light, solid line. Facing reversal boundaries are shown by light dash-dot lines; these represent axial traces of F_1 isoclinal folds. MPSZ (solid black)—Manitou Stretch-Pipestone Lake shear zone. HapLand—location of Happy Landing Lodge.* **15.2b.** *Stereogram of poles to F_2 cleavage (dots). There are two clusters: poles to general cleavage directions S2a and S2b.* **15.2c.** *Generalized interpretative sketch of F_2 folds with kink-band orientations S2a and S2b. S0 is bedding. Heavy arrows show variable way-up depending on which limb of an F_1 fold the F_2 folds occur. Such folds commonly occur with a short limb width of several metres, just a little large to see on most individual outcrops.* **15.2d.** *Variations in structure within kink-bands of S2a-type, ranging from simple over-rotation to parasitic kinks to kink-band boundary shearing.*

lowed basalts (PB) (although BAF does trend parallel to its contact with TBS). Thus, during this field season, the contact relationship between TBS and BAF was exposed by semi-continuous stripping for 70 m southwest from a shoreline outcrop on the southwestern shore of Thompson Bay (location A, Figure 15.2). Here, lowermost in the BAF sequence, is a massive and pillowed, amygdaloidal and plagioclase phyric, basaltic andesite flow 50 m in thickness. The plagioclase phenocrysts are lath-shaped, unlike the more equant shapes seen in the underlying PB. Pillows, somewhat irregular and elongate parallel to foliation, suggest a northeast facing. At the top surface of the flows there is an abrupt transition to bedded tuff that is locally developed at the contact and is overlain by a 4 m thick unit of low-matrix, homolithic, intermediate lapilli-tuff. This lapilli-tuff unit is overlain by a 1 m thick, crudely-bedded to well cross-bedded tuff and subordinate lapilli-tuff. Over this is 2.5 m of unstratified low-matrix lapilli-tuff. Clasts in this unit are rounded to angular and vary from plagioclase or pyroxene phyric to non-phyric and aphanitic. These volcanic rocks are overlain by 2 m of thin to medium-bedded fine wacke-mudstone. Capping the exposed sequence at the water line is an intermediate flow with pillow-like structures and flow breccia with hyaloclastic fragments and possibly aquagene tuff. The base of the flow has brecciated the underlying sediments which locally appear baked and have porphyroblasts resembling andalusite. The interfingering of volcanic and sedimentary rock in this outcrop suggest that BAF is transitional and conformable with TBS.

The relationship between BAF (and therefore TBS) and PB is more difficult to ascertain. Pillow tops in PB indicate that south of James Bay, PB faces in the direction opposite to BAF (Figure 15.2) whereas between Thompson Bay and James Bay, strikes obtained from pillows suggest that PB trends perpendicular to BAF and TBS. The contact between BAF and PB has not been found in outcrop, however, near the inferred contact at two locations (Bs on Figure 15.2), there is an unusual fractured massive mafic flow. The fractures are up to 1 cm wide and are normally filled by comminuted mafic material, although some are occupied by calcite. The resulting rock is an incomplete breccia of centimetre size fragments. This rock may be fault breccia; if it is, then there is the suggestion that BAF and PB are in fault contact or alternatively, the breccia could be a feature of paleo–weathering at an unconformity on PB. More work is required to determine the nature of this unusual rock and to elucidate the contact relationship between BAF and PB.

STRUCTURAL GEOLOGY

Strata between the Wabigoon Diapiric Axis and the Manitou Stretch–Pipestone Lake shear zone (MPSZ, Figure 15.2) are complexly folded and faulted. The interpretation of the structure is also encumbered by the paucity of way–up criteria in some areas and by the added complexity due to the competency contrast between the sediments (TBS) and volcanics (BAF and PB). Edwards (1983a) interpreted that TBS and apparently BAF were folded into a tri–lobed synclinal structure, complicated in the sediments by parasitic folds of short wavelength. Based on the current field work, this preliminary interpretation can now be augmented as follows.

Two fold phases are present in TBS: F_1, a series of vertical, isoclinal folds whose axial traces define the facing direction boundaries shown on Figure 15.2a; and F_2, a moderately developed, conjugate, micro– to meso–scale group of folds whose geometric features are shown on Figures 15.2b to 15.2d. Mapping and analysis of folds are not yet complete in the sediments and structural analysis has not yet begun in the volcanic rocks.

We tentatively conclude that the Thompson Bay sediments (TBS) and immediately underlying basaltic–andesitic fragmental rocks and subordinate flows (BAF) seem to have been deposited, in part, on an inverted series of pillowed basalts (PB).

SUGGESTIONS FOR FURTHER WORK

The present knowledge of the structure of supracrustal belts in the Wabigoon Subprovince is inadequate. Without a comprehensive understanding of the nature of the deformation, there can be little understanding of Archean tectonism. This work seeks to clarify some of the local elements of strata and structure that may have wide tectonic significance. The immediate goals of further field work should be to identify and examine the contact between BAF and PB to determine if it is a fault contact or an unconformity, with the younger rocks overlying upside–down strata. Dominant and parasitic folds, cleavage, and fracturing in TBS and BAF should be studied further and contrasted with similar features in PB for regional strain analysis.

More broadly, future work should aim at understanding crustal evolution in this part of the Wabigoon Subprovince. For example, if PB were inverted before BAF and TBS were deposited, then what were the tectonic processes that resulted in the early overturning of the strata and the subsequent tri–lobed folding of TBS? What was the relative timing of the deformational events? Can the deformational events be related to similar events elsewhere in Wabigoon Subprovince or Superior Province?

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Wabigoon Subprovince

16. Geological Studies in the Wabigoon Subprovince, Superior Province

G.W. Johns

Geologist, Precambrian Geology Section, Ontario Geological Survey, Toronto.

Systematic geological investigations of the greenstone–granite terrains in the Wabigoon Subprovince are designed to provide a quality data base for the Ontario mineral industry. Emphasis is put on detailed mapping at a scale of 1:15 840. These traditional quarter mile maps form the basis for mineral exploration, synoptic mapping, mineral deposit studies and research on greenstone belt development.

Over the last few years the Ontario Geological Survey has conducted several projects mainly in the Lake of the Woods, the Sioux Lookout–Dinorwic, and the Lower Manitou Lake areas: a) mapping completed in the Monument Bay area in 1987 by Morrice and MacMaster (1987) discovered previously unknown gold mineralization (the area has subsequently attracted much attention); b) continuing work by John Ayer in the Lake of the Woods area has resulted in several new gold showings since 1982, as well as a better understanding of the volcanic stratigraphy; c) detailed mapping and special studies conducted in the Sioux Lookout–Dinorwic area by Ben Berger and Leslie Chorlton have re-evaluated the structural and stratigraphic controls to mineralization.

This year seven projects were carried out within the subprovince; four in the western Wabigoon and three in the eastern Wabigoon. The emphasis has been to fill the gaps in the present data base and complete ongoing special studies.

The detailed mapping of the Lake of the Woods Greenstone Belt is now almost complete at the 1:15 840 scale (Ayer this volume) and the remaining gaps in mapping will be filled during the synoptic study that will subsequently be carried out. The lack of up-to-date information that existed between the Straw Lake area (Edwards 1983) and the Upper Manitou–Lower Manitou Lakes area (Blackburn 1982) was filled in this year by the mapping of Berger (this volume) and Smith (this volume). Leslie Chorlton (this volume) completed the structural and metallogenic study in the Sioux Lookout–Dinorwic area.

In the eastern Wabigoon Subprovince east of Lake Nipigon, Kresz and Zayachivsky (this volume) have presently completed 1:15 840 scale mapping in the Beardmore–Geraldton belt. The Long Lac area (Kresz and Zayachivsky 1987) and the Seagram Lake area (Kresz and Zayachivsky, this volume) are east of the Geraldton gold camp and a high potential for gold mineralization is indicated by this recent mapping. Howard Williams' examination (this volume) of the boundary between the Quetico and the Wabigoon Subprovinces has implications for the development of subprovince boundaries and gold mineralization possibly associated with these boundaries.

Work by Carter (this volume) and Sutcliffe and Smith (this volume) while not directly involved with the Wabigoon Subprovince are in geographic proximity and hence are included in this section of the Summary of Field Work.

The 1988 field season resulted in significant new information coming to light as the result of the detailed mapping projects. John Ayer mapping in the west–central Lake of the Woods area (Falcon Island area) has traced the Monument Bay shear system, that contains several gold occurrences (Morrice and MacMaster 1987), into the northern portion of the Falcon Island area. As well, highly metamorphosed felsic volcanics, previously thought to be part of the Sabaskong Batholith (Blackburn 1981), were outlined in the southern portion of the area.

Ben Berger mapping in the Manitou Stretch area has been able to correlate volcanic lithology between the Straw Lake area (Edwards 1983) and the Upper Manitou–Lower Manitou Lakes area (Blackburn 1982). Several previously unknown rock units and alteration zones with gold potential have been outlined. The map area to the south examined by Mark Smith (Vista Lake area) contains several previously unknown deformation zones that have potential for gold mineralization. Smith also outlined a previously unknown series of pyroclastic rocks.

Leslie Chorlton has made note of the base–metal potential in the central volcanic complex of the Neepawa Group in the Sandybeach Lake area. As well, she determined that gold mineralization is controlled by stage three shear zones, folds, and fracture zones.

In the Seagram Lake area east of Long Lac, Dave Kresz and Borys Zayachivsky (this volume) have outlined previously unknown deformation zones that are along strike with those zones hosting the gold mineralization in Geraldton.

The Wabigoon Subprovince is one of the best exposed granite–greenstone terrains in Ontario and significant portions of it have been covered by recent geological mapping. Several areas have also been covered by regional synoptic studies (Trowell 1983;

Blackburn 1982). Current work includes the Rowan–Kakagi Lakes area and future synoptic studies include the Lake of the Woods greenstone belt. A large–scale synthesis of the Wabigoon Subprovince is to be included in the 1:1 000 000 scale Geology of Ontario map that is currently in preparation. This data base will be used to initiate and complete several special studies by both the Ontario Geological Survey and Ontario's Universities, emphasizing, among other topics, structural geology, volcanology, greenstone stratigraphy, metallogeny and alteration, geochronology, and greenstone belt evolution.

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17. Project Number 86–21. Gold Studies in the Manitou Lakes–Stormy Lake Belt, Districts of Kenora and Rainy River

J.R. Parker[1] **and M. Perrault**[2]

[1]Project Geologist, Ministry of Northern Development and Mines, Resident Geologist Office, Kenora.

[2]Geological Assistant, Ministry of Northern Development and Mines, Resident Geologist Office, Kenora.

INTRODUCTION

This report summarizes results of 1988 field work as part of an ongoing study of gold mineralization in the Manitou Lakes–Stormy Lake belt of the Wabigoon Subprovince. The belt is situated 48 km southwest of Dryden and is bounded by Latitudes 40°15′ to 49°29′ and Longitudes 93°00′ to 92°12′. Field work during the summer of 1988 was concentrated between Mosher Bay of Upper Manitou Lake in the west, and Stormy Lake in the east, and consisted of detailed examinations of all known gold occurrences and prospects, reconnaissance sampling, and detailed mapping at a scale of 1:4800 in the vicinity of Sunshine Lake. The location of the area is shown if Figure 17.1. The aim of the field work is to assess the economic potential of the belt, and to determine the relationship of gold mineralization to stratigraphy, structure, and the tectonic evolution of the Manitou Lakes–Stormy Lake belt.

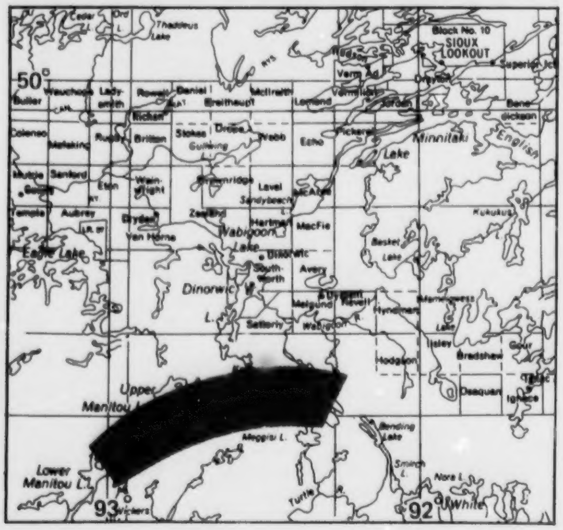

Cedar L.
Ord L.
Thaddeus Lake
Block No. 10
SIOUX LOOKOUT
Superior Jct.
50°
Wauchope
Lady-smith
Rowell
Daniel
McIlraith
Breithaupt
Lomond
Vermilion
Jordan
Drayton
Bene-dickson
Richan
Colenso
Mafeking
Rugby
Britton
Stokes
Drope
Webb
Echo
Pickerel
Minnitaki
Lake
English
Gullwing
Mutrie
Sanford
Eton
Wain-wright
Brownridge
Laval
Sandybeach
McAree
Kukukus
Temple
Aubrey
Zealand
Hartman
MacFie
Van Horne
Wabigoon
Lake
Eagle Lake
Basket Lake
South-worth
Avery
Dinorwic
L.
Sattertly
Melgund
Wabigoon R.
Hyndman
Lake
Hodgson
Bradshaw
Gour
Upper
Manitou L.
Dasquan
Ignace
Bending Lake
Meggisi L.
Lower Manitou L.
Smirch L.
Nora L.
Turtle R.
93°
Vickers
92°
White

Figure 17.1. *Location map for the Manitou Lakes–Stormy Lake belt. Scale: 1:1 584 000 or 1 inch to 25 miles.*

The Manitou Lakes–Stormy Lake greenstone belt is an assemblage of metavolcanic and metasedimentary rocks intruded by quartzporphyry stocks, gabbro sills, and lamprophyre dikes and sills. Gold mineralization is widespread throughout the area of investigation.

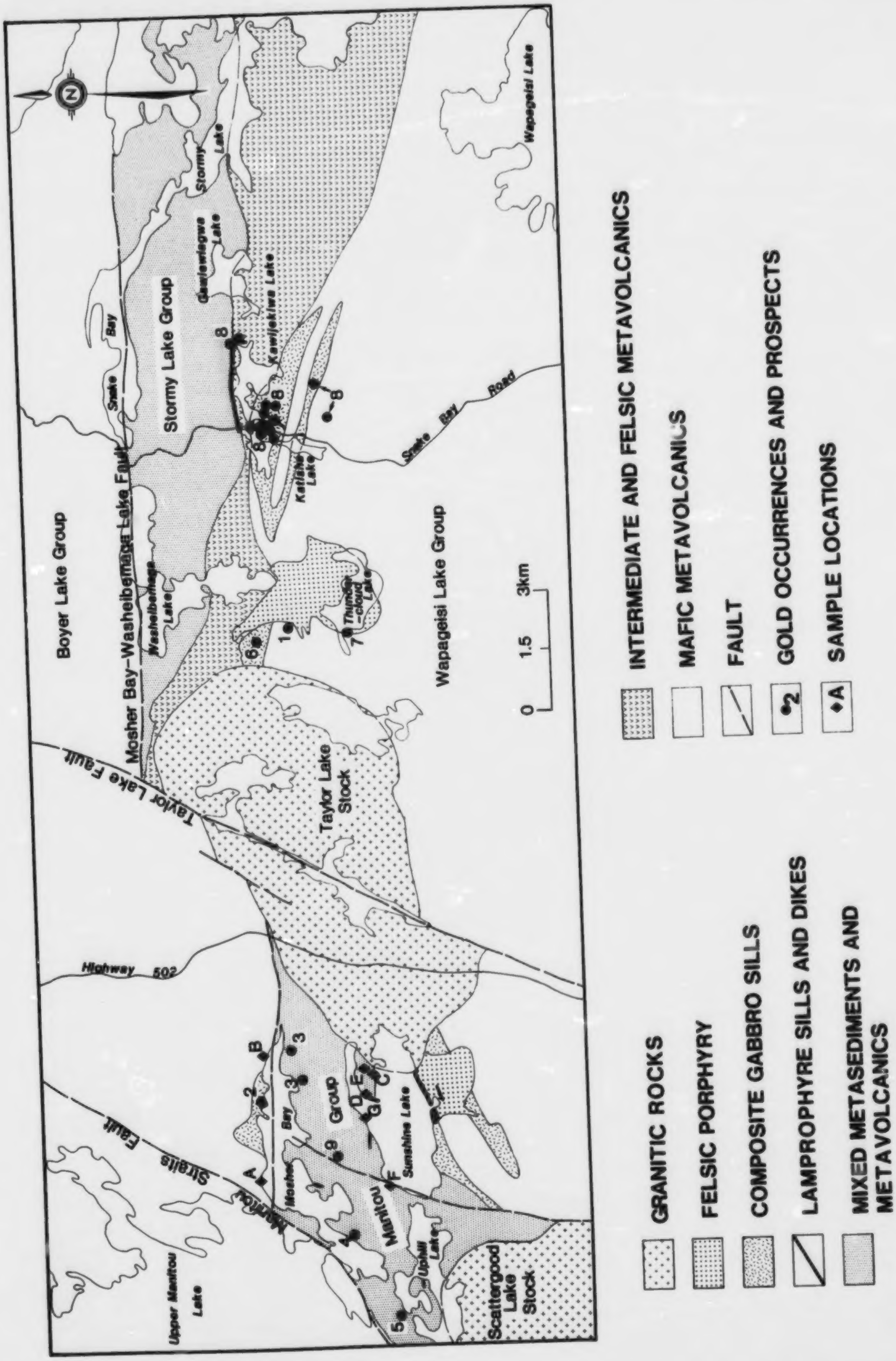
MINERAL EXPLORATION

Exploration for gold began around 1897 in the Manitou Lakes–Stormy Lake belt, subsequent to discoveries of gold made on Upper Manitou Lake.

Several shafts and an adit were developed between 1897 and 1905 at the Giant Mine (*see* Figure 17.2, Number 3) (Carter 1904; Blackburn 1981), south of Mosher Bay, and some limited work was conducted at the Big Dick Prospect (*see* Figure 17.2, Number 2), on the northeast shore of Mosher Bay, in 1897 and 1933 (Thomson 1934). Channel sampling at the Giant Mine conducted by Cochrane Oil and Gas Limited during 1983 and 1984, resulted in assays as high as 0.599 and 0.508 ounce gold per ton across two, 0.8 m wide, parallel quartz veins, and 0.019 ounce gold per ton across 1 m of sheared wall rock (Cochrane Oil and Gas Limited, Assessment Files, Resident Geologist Office, Kenora).

The Pelham Prospect (*see* Figure 17.2, Number 6), southwest of Washeibemaga Lake, was discovered in 1937, where exploration continued intermittently between 1938 and 1974 (Blackburn 1981). Many good gold values have been obtained from chip samples taken across several of the mineralized zones at the Pelham Prospect such as, 0.125 ounce gold per ton across 2.4 m, 0.43 ounce gold per ton across 1.1 m, and 0.46 ounce gold per ton across 4.3 m, with grab samples assaying over 5.0 ounces gold per ton (Osisko Lake Mines Limited, Assessment Files, Resident Geologist Office, Kenora). Esso

This project A.6.8 is part of the five year Canada-Ontario 1985 Mineral Development Agreement (COMDA), a subsidiary agreement to the Economic and Regional Development Agreement (ERDA) signed by the governments of Canada and Ontario.


N
Boyer Lake Group
Mosher Bay–Washeibemaga Lake Fault
Stormy Lake Group
Snake Bay
Stormy Lake
Gawiewiagwa Lake
Kawijekiwa Lake
Katisha Lake
Snake Bay Road
Washeibemaga Lake
Thunder-cloud Lake
Wapageisi Lake Group
Wapageisi Lake
0 1.5 3km
Taylor Lake Fault
Taylor Lake Stock
Highway 502
Manitou Straits Fault
Mosher Bay Group
Manitou
Sunshine Lake
Upper Manitou Lake
Uphill Lake
Scattergood Lake Stock
A
B
C
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GRANITIC ROCKS
FELSIC PORPHYRY
COMPOSITE GABBRO SILLS
LAMPROPHYRE SILLS AND DIKES
MIXED METASEDIMENTS AND METAVOLCANICS
INTERMEDIATE AND FELSIC METAVOLCANICS
MAFIC METAVOLCANICS
FAULT
GOLD OCCURRENCES AND PROSPECTS
SAMPLE LOCATIONS

Figure 17.2. *General Geology and Gold Deposits of the Manitou Lakes–Stormy Lake belt.*

Minerals Canada and Noranda Incorporated are the companies to most recently conduct exploration programs at the Pelham Prospect. A drill program conducted by Noranda in a joint venture with Tundra Gold Mines Limited, on their portion of the prospect, resulted in drill intersections of 0.16 ounce gold per ton across 3 m and 0.12 ounce gold per ton across 2 m (Tundra Gold Mines Limited, News Release, March 21, 1988). Noranda Incorporated has also conducted recent exploration programs on the Armstrong (*see* Figure 17.2, Number 1) and Renders (*see* Figure 17.2, Number 7) occurrences south of the Pelham Prospect.

Esso Minerals Canada has been exploring for gold between Katisha and Stormy lakes (*see* Figure 17.2, Number 8) since 1983, following the discovery of gold at Katisha Lake by Esso geologists. Diamond drilling on several mineralized zones has indicated that gold occurs within numerous narrow sections assaying as high as 0.14 ounce gold per ton across 0.84 m, 0.26 ounce gold per ton across 0.15 m, and 0.5 ounce gold per ton across 0.54 m (George Cross News Letter, September 13, 1986).

Voyager Exploration Limited conducted gold exploration near Gawiewiagwa and Kawijekiwa Lakes, immediately west of Stormy Lake, between 1983 and 1985. Gold assays from grab and channel samples taken from trenches by the company were generally low (Voyager Explorations Limited, Assessment Files, Resident Geologist Office, Kenora).

Jalna Resources Limited conducted an extensive reconnaissance survey of the Manitou Lakes–Stormy Lake belt during 1983. No significant gold mineralization was discovered, although many anomalous gold values were obtained from extensive lithogeochemical sampling (Jalna Resources Limited, Assessment Files, Resident Geologist Office, Kenora).

PREVIOUS GEOLOGICAL WORK

The area was first mapped by J.E. Thomson in 1932, as part of the Manitou–Stormy Lakes Area (Thomson 1934), a reconnaissance survey extending from Lower Manitou Lake to Stormy Lake. C.E. Blackburn mapped the Lower Manitou–Uphill Lake Area (Blackburn 1976) during 1972 and the Boyer–Meggisi Lakes Area (Blackburn 1981) during 1974 and 1975, followed by mapping, during 1980 and 1981, of the Kawashegamuk Lake Area by D.U. Kresz and C.E. Blackburn (Kresz *et al.* 1982a, b; Kresz 1987). The Manitou Lakes–Stormy Lake belt was included in an airborne electromagnetic and magnetic survey flown over the Manitou–Stormy Lakes Area and published in 1980 (OGS 1980).

GENERAL GEOLOGY

The Manitou–Stormy Lake belt is a generally east trending assemblage of metavolcanic and metasedimentary rocks which extends for approximately 80 km from Lower Manitou Lake in the west to Bending Lake in the east. Blackburn (1982) has outlined the stratigraphy of the belt which is comprised of mafic and felsic metavolcanics of the basal Wapageisi Lake group, unconformably overlain by metavolcanic and metasedimentary rocks of the Manitou and Stormy Lake groups (*see* Figure 17.2). The Boyer Lake group (*see* Figure 17.2) to the north is in contact with the Stormy Lake and Manitou groups along the east-trending Mosher Bay–Washeibemaga Lake Fault (*see* Figure 17.2) and consists of a monotonous sequence of pillowed mafic flows. The metavolcanics–metasedimentary sequence has been intruded by the Tayler and Scattergoed Lake Stocks (*see* Figure 17.2).

Intermediate to felsic pyroclastics and epiclastics at the top of the Wapageisi Lake group have been intruded by subvolcanic, felsic, quartz porphyry stocks, such as the Thundercloud Porphyry (*see* Figure 17.2), which has been interpreted to be the source of porphyritic felsic metavolcanics in the immediate area (Blackburn 1981). The Sunshine Lake Porphyry (*see* Figure 17.2) intrudes mafic flows at the top of the Wapageisi Lake group and may also be a felsic, subvolcanic intrusion (Blackburn 1981). The top of the Wapageisi Lake group is also intruded by a series of lamprophyre and composite gabbro sills. Lamprophyre dikes and sills also intrude the Sunshine Lake Porphyry, and metasediments and metavolcanic rocks of the Manitou Lake group.

Three predominant phases of shear zone and fault development occur in the area studied. Early north and northwest-trending shear zones generally occur within the Wapageisi Lake group and are intersected by east and east-northeast-trending shear zones which occur in the Wapageisi Lake, Stormy Lake and Manitou groups. Numerous, late, northeast-trending brittle faults intersect all rock types and structures. The most prominent of these is the Taylor Lake Fault (*see* Figure 17.2), where a sinistral displacement of at least 2 km has been estimated (Blackburn 1981). The northeast-trending Manitou Straits Fault extends through the southwest corner of Mosher Bay and is associated with intense, northeast shearing.

CHARACTERISTICS OF GOLD MINERALIZATION

The gold occurrences and prospects examined by the author are concentrated in the vicinity of Mosher Bay and Washeibemaga and Katisha lakes.

The known gold occurrences and prospects near Mosher Bay consist of the Giant Mine (*see* Figure 17.2, Number 3), "Ten Trench" area (9), Big Dick Occurrence (2), H.W. 167 Occurrence (4), and the H.W. 170 Occurrence (5). All of the gold occurrences and prospects, with the exception of the Big

Dick Occurrence, are hosted by meta–arenites, wackes and polymictic conglomerates of the Manitou group. The Giant Mine, H.W. 167, and H.W. 170 Occurrences are situated within east–northeast–trending shear zones hosting sheared porphyritic, felsic dikes. The metasediments and dikes are fissile, sericitized, and iron carbonatized and generally contain less than 2 percent disseminated pyrite. Quartz veins are shear zone hosted and/or hosted by northwest–trending tension fractures and rarely contain more than 1 percent pyrite. At the occurrence named the "Ten Trench" area by Jalna Resources, southwest of Mosher Bay, the meta–arenite host rocks are not sheared, but contain abundant 1 to 5 cm wide, tension fracture–hosted quartz veinlets, which strike in a general north–northeast direction.

The Big Dick Occurrence (*see* Figure 17.2, Number 2), on the north shore of Mosher Bay, consists of a strong, narrow, northeast–trending shear zone, extending through the contacts of an intensely altered gabbro with a coarse–grained quartz–feldspar porphyry dike. The gabbro is fissile, intensely iron carbonatized, pyritic, and chloritized. Quartz veins are shear zone and tension fracture–hosted and contain altered fragments of wall rock, disseminated pyrite, arsenopyrite, and minor chalcopyrite.

The author sampled all the occurrences and prospects described above, however, most of the samples analyzed yielded only slightly anomalous gold values. The best result was from a sample taken from a sheared felsic dike in the vicinity of the H.W. 167 Occurrence, which contained 1495 ppb gold. A grab sample of pyritic meta–arenite taken from a pit at the "Ten Trench" area contained 1470 ppb gold. A grab sample of pyritic, quartz vein material taken from the adit at the Giant Mine had 1300 ppb gold, and a sample of a pyritic, quartz–feldspar porphyry dike at the adit contained 1385 ppb gold (Geoscience Laboratories, Ontario Geological Survey, Toronto).

The author also sampled silicified, pyritic, amygdaloidal, massive and pillowed mafic flows at the northwest corner of Mosher Bay, indicated on geological Map 2437 (Blackburn 1981). The mafic flows along the lakeshore are sheared, fissile, carbonatized, dark green to pale green–gray, and variably silicified along hairline fractures. Abundant seams of disseminated pyrite occur throughout the mafic flows. Two grab samples of the pyritic mafic flows analyzed had 85 ppb gold and 1640 ppb gold (*see* Figure 17.2; Location A). A grab sample of epidotized, pyritic, mafic flows, taken on the northeast shore of Mosher Bay, contained 60 ppb gold (*see* Figure 17.2; Location B) (Geoscience Laboratories, Ontario Geological Survey, Toronto).

Abundant sulphide mineralization, alteration, and structural disruption is relatively minimal at Sunshine Lake; however, grab samples taken by the author during mapping at Sunshine Lake, did yield anomalous and low gold values. A pyritic metasediment analyzed yielded 50 ppb gold (*see* Figure 17.2, Location C), a sample of intermediate crystal tuff hosting pyrite and chalcopyrite contained 39 ppb gold (*see* Figure 17.2, Location D), a sample of pyritic, carbonatized gabbro yielded 130 ppb gold (*see* Figure 17.2, Location E), a pyritic, dacitic flow contained 210 ppb gold (*see* Figure 17.2, Location F), and a sample of pyritic, carbonatized mafic flows, taken from a small point on the north shore of Sunshine Lake, assayed 0.19 ounce gold per ton (*see* Figure 17.2, Location G) (Geoscience Laboratories, Ontario Geological Survey, Toronto).

The gold occurrences and prospects in the vicinity of Washeibemaga and Katisha lakes commonly occur in the vicinity of the Thundercloud Porphyry at Washeibemaga Lake, and within composite gabbro sills which intrude the calc–alkalic, felsic and intermediate, pyroclastic sequence at the top of the Wapageisi Lake group (*see* Figure 17.2).

The Snake Bay Prospect (*see* Figure 17.2, Number 8), near Katisha Lake, consists of thirteen gold–bearing zones discovered by Esso Minerals Canada geologists. The most significant mineralized zones are hosted by 1 to 15 m wide, north, and northwest–trending shear zones, in magnetite–bearing, composite gabbro sills. The shear zones have been pervasively and intensely iron carbonatized, and host carbonate veins up to 5 m in width. The carbonate alteration is postdated by pervasive silicification and quartz veining associated with abundant pyrite, arsenopyrite, and gold mineralization. The silicified zones are narrow, pod–shaped, and concentrated in flexures and wider sections of the shear zones. A second stage of silicification, consisting of irregular, barren quartz stockworks, overprints the carbonate veining and first stage of silicification.

All of the mineralized zones at the Snake Bay Prospect were sampled by the author, with assay values ranging from 5 ppb gold to 0.5 ounce gold per ton and with arsenic as high as 10.5 percent (Geoscience Laboratories, Ontario Geological Survey, Toronto).

Biotite– and pyroxene–phyric lamprophyre dikes are hosted by the mineralized shear zones and the east–trending shear zones. A carbonatized, vesicular, lamprophyre dike at the Twilight Zone intersects the silicified, mineralized zones. Although some of the lamprophyre dikes are sheared and carbonatized, it is clear that they were intruded late in the structural development of the shear zones and postdate the gold mineralizing event.

The geology of the Pelham Prospect (*see* Figure 17.2, Number 6), southwest of Waheibemaga Lake, has been described by Blackburn (1981) as a complex succession of mafic flows and pyroclastics alternating with lenses of felsic flows, ash flows, coarse pyroclastic rocks and very minor epiclastics. The gold–bearing zones are hosted by a coarse–grained, magnetite-bearing, gabbro sill intruded by the Taylor Lake Stock to the west, and the Thundercloud porphyry to the east. The gold-bearing zones have various widths, trend northeast, northwest, and east, and consist of complex networks of micro-fractures. Alteration consists of pervasive silicification, biotitization, epidotization associated with variable amounts of disseminated pyrite, pyrrhotite, chalcopyrite, and gold. Epidote is closely associated with the mineralized zones, and commonly occurs in numerous crisscrossing veinlets which form extensive "spider web" textures in weathered outcrop surfaces.

The Armstrong Occurrence (*see* Figure 17.2, Number 1) consists of a poorly sorted, heterolithic tuff breccia intercalated with pillowed, mafic flows and felsic, porphyritic, pyroclastic rocks associated with the Thundercloud Porphyry, east of the occurrence. The breccia and mafic flows are silicified, gossan-stained, epidotized, and contain disseminated pyrite. The mafic flows contain abundant crisscrossing epidote veinlets similar to those at the Pelham Prospect. Gold mineralization is associated with pyrite in the altered tuff-breccia and mafic flows. No obvious structural disruption or quartz veining was observed by the author. Chip samples taken across the zone gave assay values ranging between 0.08 ounce gold per ton across 0.9 m, and 0.32 ounce gold per ton across 1 m (Fornieri Option, Assessment Files, Resident Geologist Office, Kenora). A grab sample of the pyritic, heterolithic tuff-breccia, taken by the author, yielded 1870 ppb gold, while two samples of the epidotized, pyritic, mafic flows contained 520 ppb gold and 725 ppb gold (Geoscience Laboratories, Ontario Geological Survey, Toronto).

RECOMMENDATIONS FOR EXPLORATION

Gold mineralization is widespread throughout the Manitou Lakes-Stormy Lake belt. Within the area under discussion, gold is associated with shear zone—and fracture-hosted quartz veins in metasedimentary rocks, and with pervasively silicified shear and fracture zones in gabbro sills. Alteration predominantly consists of intense iron carbonatization overprinted by silicification and sulphide mineralization, or intense epidote veining, biotitization, and sulphidation.

Detailed prospecting should be conducted in the vicinity of Mosher Bay and Sunshine Lake, where results of the author's sampling indicate that anomalous and low grade gold mineralization occurs in a variety of variably altered, pyritic rock types.

Exploration should be conducted between Gawiewiagwa and Stormy lakes in search of mineralized zones similar to those at the Snake Bay and Pelham prospects. The metasedimentary rocks of the Manitou and Stormy Lake groups should also be more thoroughly examined for shear zone and/or fracture-hosted, gold-bearing quartz veins.

CONCLUSION

The gold deposits within the upper part of the Wapageisi Lake group (i.e. the Snake Bay and Pelham prospects), are spatially and genetically related to a major tectonic zone that was the focus for shear development, and intrusive and hydrothermal activity. The stratigraphic succession suggests that there was an evolution from deepwater, mafic, tholeiitic, submarine flows, with little or no clastic sedimentation, to more violent, felsic, calc-alkalic pyroclastic volcanism, some of which was subaerial. Clastic metasediments, associated with felsic volcanic rocks, are of proximal, alluvial fan to fluvial facies, which grades both laterally and upward into distal submarine fan facies. The thick, mafic flow sequences probably formed during rifting of an early, undetermined basement (Blackburn 1980). Blackburn (1980) suggested a model whereby subsequent calc-alkalic volcanism resulted from subduction of the early mafic flows, accompanied by proximal sedimentation on the flank of rising, felsic, volcanic arcs, and distal sedimentation in adjacent troughs possibly above subduction zones. According to this model, the Mosher Bay Waheibemaga Lake Fault may represent a reactivated, synvolcanic basin-margin fault.

Shear zones at the Snake Bay Prospect were developed after both calc-alkalic, felsic volcanism but before flanking sedimentation. This shearing was followed by carbonate veining and alteration (Moreton and Gerber 1985). Later silicification accompanied by arsenopyrite, pyrite, and gold, overprinted the carbonate-bearing zones. Lamprophyre sills and dikes were intruded late in the development of the shear zones and postdate gold mineralization.

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18. Project Number 88–16. Geology of the Falcon Island Area, Lake of the Woods, District of Kenora

J.A. Ayer

Geologist, Precambrian Geology Section, Ontario Geological Survey, Toronto.

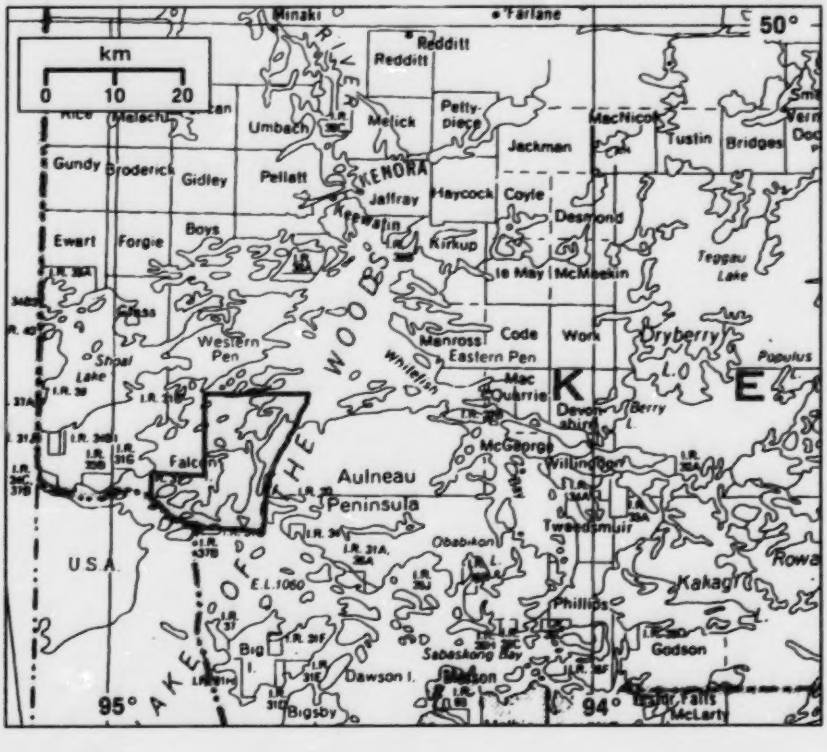
INTRODUCTION

Field investigations in the summer of 1988 were within the west–central portion of the Lake of the Woods area, southwest of the town of Kenora. The Falcon Island area is part of an ongoing program to complete detailed mapping of the Lake of the Woods greenstone belt which is situated at the western end of the Wabigoon Subprovince of the Superior Province. Little was known of the geology of the Falcon Island area prior to this work as only parts of the area had been mapped at reconnaissance scales (Lawson 1885; Greer 1931; and Thomson 1937).

An irregular–shaped area of about 270 km² bounded by the outside limits of latitudes 49°19′N and 49°30′N and longitudes 94°34′W and 94°52′W was mapped at a scale of 1:15 840 (Figure 18.1). Access to the area is by boat either from the town of Kenora, located about 40 km northeast of the centre of the map area, or from Angle Inlet, Minnesota, located about 20 km to the southwest.

MINERAL EXPLORATION

Information on exploration activity has been obtained from the Resident Geologist's Files, Ontario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Populus
Eastern Pen
Whitefish
Shoal Lake
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Willingdon
Falcon
Aulneau
Peninsula
Tweedsmuir
Obabikon
U.S.A.
E.L.1060
Kakagi
Rowan
Phillips
Big I.
Sabaskong Bay
Godson
Dawson I.
Bigsby
95°
94°
Falls
McLarty
LAKE OF THE WOODS
RIVER

Figure 18.1. *Location Map for the Falcon Island area.*

CANADA
ONTARIO

This project A.6.1 is part of the five year Canada-Ontario Mineral Development Agreement (COMDA), a subsidiary agreement to the Economic and Regional Development Agreement (ERDA) signed by the governments of Canada and Ontario.

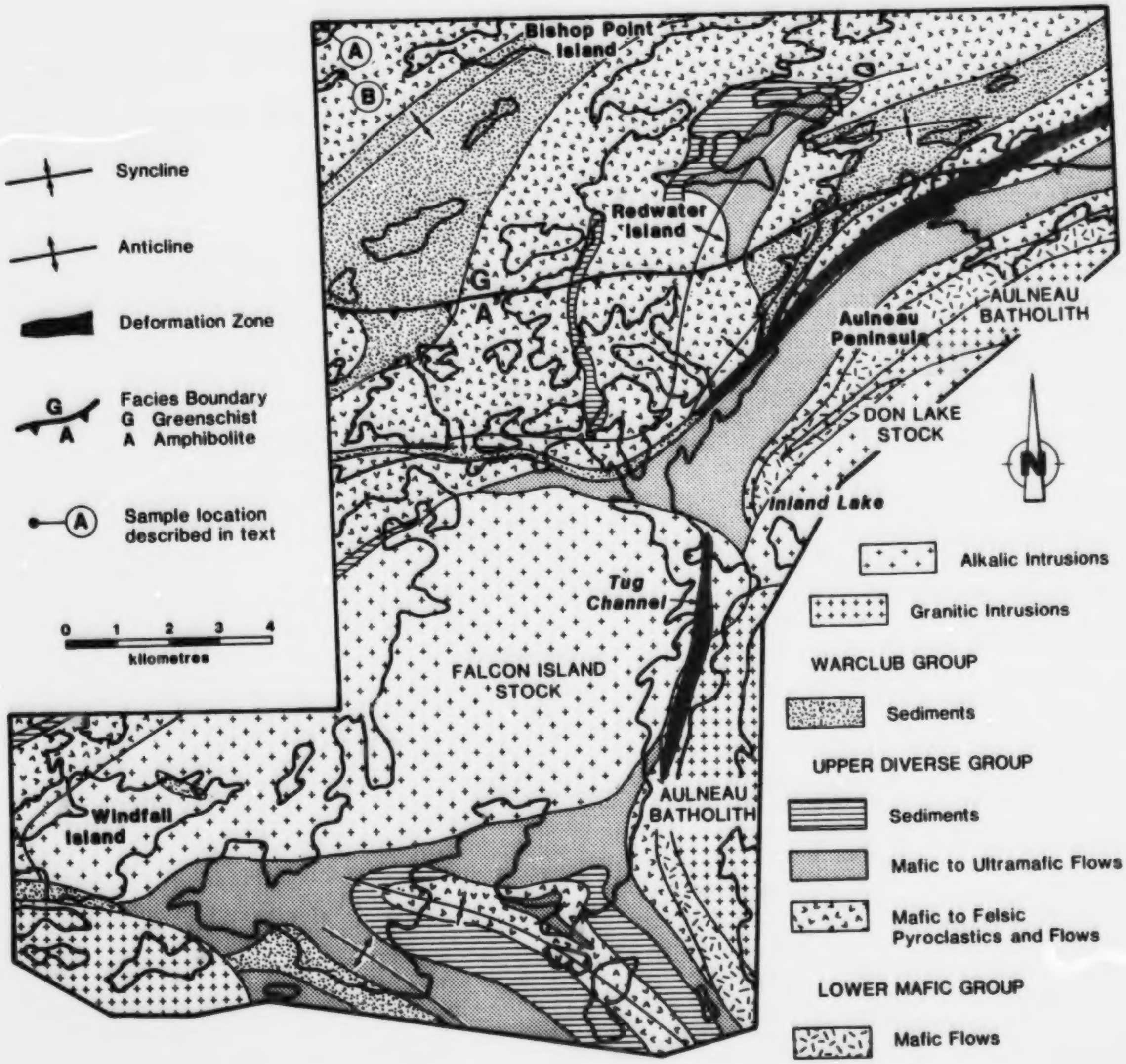
Ministry of Northern Development and Mines, Kenora.

At the time of writing (September 1988) there are no active claims within the map area. However, in the Momument Bay area, west of the Falcon Island area there are a large number of claims, currently being explored for gold, staked on a northeast–trending mineralized zone which extends into the northwestern part of the map area.

The Mack 26/27 Occurrence located on the eastern side of the Tug Channel, Lake of the Woods, southwest of Inland Lake (Figure 18.2) is the only gold showing recorded within the map area. This showing was held by the Bullion Mining Company in the late 1900s. Coleman (1898) reported that a white quartz vein, five– to six–feet (1.5 to 1.8 m) wide, was stripped for a total of 70 feet (21.3 m) but no further development work was done. It was not located during the present survey.

Reported exploration on the Falcon Island Stock includes three geological traverses made in 1966 by the Kenora Resident Geologist to investigate for possible carbonatites in the alkalic intrusive complex; and, in 1970, Kennco Explorations (Canada) Limited conducted a ground magnetometer survey on a group of nine claims on the northwestern side of the stock.

Two industrial–mineral occurrences are situated within the map area (Blackburn 1981). A pegmatite dike near Mica Point on the southern side of Falcon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A Amphibolite
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FALCON ISLAND STOCK
Windfall Island
AULNEAU BATHOLITH
Alkalic Intrusions
Granitic Intrusions
WARCLUB GROUP
Sediments
UPPER DIVERSE GROUP
Sediments
Mafic to Ultramafic Flows
Mafic to Felsic Pyroclastics and Flows
LOWER MAFIC GROUP
Mafic Flows

Figure 18.2. *General Geology of the Falcon Island area.*

Island was mined for mica in 1885. During 1926–1927, it was quarried for feldspar by the Winnipeg Roofing Company with a production of a few hundred tons. In 1975, F. Thorgrimson (Prospector, Keewatin) excavated a small opencut on talcose soapstone southeast of Coste Island and a small amount was used for decorative carvings (Storey 1986).

GENERAL GEOLOGY

Parts of the present map area (Figure 18.2) are included in maps produced by Lawson (1885), Greer (1931), and Thomson (1937). The map area adjoins the Western Peninsula area (Davies 1983) to the north, the Monument Bay area (Morrice and MacMaster 1988) to the west, and the Chisholm Island area (Ayer *et al.* 1988) to the east.

The area is underlain by Archean supracrustal and intrusive rocks within the western portion of the Wabigoon Subprovince. Supracrustal rocks consist of volcanic, sedimentary, and subvolcanic intrusive rocks metamorphosed to greenschist facies in the north and amphiboloite facies in the central and southern parts of the map area. The supracrustal succession is intruded by several large granitoid bodies. The Archean rocks are intruded by northwest–trending, Early Proterozoic diabase dikes.

The supracrustal rocks are subdivided into three major stratigraphic units designated the Lower Mafic group (LMG), the Upper Diverse group (UDG), and the Warclub Group (WG) (Figure 18.2). These stratigraphic units are correlative with the Chisholm Island area to the east (Ayer *et al.* 1987).

LOWER MAFIC GROUP

Rocks of this group are at the basal portion of the exposed stratigraphic section. They occur in an originally continuous horizon up to 1 km wide intruded and separated into northern and southern portions by the Aulneau Batholith (Figure 18.2). The LMG can be traced eastward into Snake Bay, Lake of the Woods, on the eastern side of the Aulneau Batholith where the group is up to 10 km thick (Johns 1987). Therefore within the map area only the uppermost part of the group is preserved. Geochemical analyses of rocks of the LMG from the Chisholm Island area (east of the current map area) indicate that the upper portion of this group consists of high–iron tholeiitic basalts (Ayer and Buck, in preparation).

Within the map area, the LMG is within the contact strain aureole of the Aulneau Batholith and thus the rocks of this group are highly deformed amphibolites. They consist of fine– to medium–grained, aphyric mafic flows with locally recognizable pillow selvages and variolites. Horizons of plagioclase–megaphyric amphibolite with highly flattened, coarse–grained plagioclase phenocrysts were observed to be up to 5 m thick at two locations; one in the northern and one in the southern portions of the LMG.

UPPER DIVERSE GROUP

Rocks of this group conformably overlie the LMG and are the most abundant of the supracrustal successions within the map area. They are a stratigraphically and structurally complex interdigitation of three subgroups: subgroup 1 (mafic to felsic pyroclastics and flows); subgroup 2 (mafic to ultramafic flows); and subgroup 3 (intervolcanic sediments) (Figure 18.2).

Subgroup 1 of the UDG (Figure 18.2) consists of a lithologically and texturally diverse intermixture of mafic to felsic volcanic rocks ranging from pyroclastics to flows. They are predominantly porphyritic with plagioclase and/or amphibolitized clinopyroxene phenocrysts in the mafic to intermediate varieties and with or without quartz phenocrysts in the felsic varieties. Pyroclastics of debris–flow origin predominate and they range from tuff–breccias to lapilli–tuffs, and tuffs and locally grade into bedded tuffs and siltstones. The volcanic fragments are heterolithic, mafic to felsic, and are set in a fine–grained, crystal–rich matrix. Mafic to intermediate flows are subordinate to the debris flows and are intimately interdigitated with the fragmentals. Flows are commonly pillowed and amygdaloidal with associated pillow breccias and flow breccias occurring locally. Massive flows are rare.

At the present time there is some controversy with regard to the geochemical nature of the mafic to felsic volcanics (subgroup 1) of the UDG. Morrice and MacMaster (1987, 1988) indicate high K_2O values for the mafic to intermediate volcanics of this subgroup from the Monument Bay area (west of the Falcon Island area) and therefore have an alkalic (shoshonitic) affinity. However, analytical results of this subgroup from the Chisholm Island Area east of the current map area display calc–alkalic trends with low K_2O values (Ayer and Buck, in preparation). The results of geochemical analyses of rocks of this subgroup collected from the Falcon Island area this summer may help to resolve this discrepancy of observations.

Rocks of subgroup 2 of the UDG (Figure 18.2) are relatively monotonous, pillowed to massive flows ranging from mafic to ultramafic in composition. The flows are fine– to medium–grained, locally variolitic, and only rarely amygdaloidal. Mafic flows are most abundant and are dark green in colour on fresh and weathered surfaces whereas ultramafic flows are volumetrically subordinate and tremolitic to talcose with a grey fresh surface and an orange–brown weathered surface. Geochemical analyses of the mafic to ultramafic flows (subgroup 2) from outside the current map area indicate that they are magnesium tholeiitic basalt to komatiitic basalt in composition (Morrice and MacMaster 1987, 1988; Ayer and Buck, in preparation).

Subgroup 3 of the UDG consists of horizons of fine-grained, thin to thickly bedded, quartz-poor, feldspathic and tuffaceous wackes interbedded with thinly laminated siltstones. Felsic to intermediate tuff-breccias and lapilli-tuffs are locally interbedded with these sediments.

WARCLUB GROUP

Sediments of the Warclub group are thickly bedded turbidites with beds ranging from 10 cm to 2 m in thickness. They are commonly normally graded from medium- to fine-grained, quartz-bearing, feldspathic wackes at the base to very fine grained mudstones at the top. AE Bouma sequences are common but all A to E divisions of the Bouma sequence may be present in some of the thicker beds. Minor intercalations of heterolithic debris flows containing volcanic and sedimentary clasts occur in the northern horizon of the WG (Figure 18.2).

INTRUSIVE ROCKS

Metamorphosed ultramafic to felsic subvolcanic sills and dikes (not shown on Figure 18.2) intrude all the supracrustal rocks. Mafic intrusions are most abundant and generally occur as gabbro sills from less than 1 m up to 1 km thick. Ultramafic intrusions up to 100 m thick range from peridotite to pyroxenite and rarely occur as differentiated sills which grade into gabbro in the upper portions. Intermediate to felsic synvolcanic dikes and sills up to 100 m thick are typically porphyritic with phenocrysts of plagioclase, with or without quartz, and feromagnesian minerals.

The Aulneau Batholith delineates much of the eastern margin of the Falcon Island area (Figure 18.2). It consists of a pretectonic, strongly foliated, medium-grained granodiorite. The northern part of the Aulneau granodiorite has been intruded by late-tectonic, weakly foliated, medium-grained monzodiorite to diorite. These later phases form a discrete, 9 km long by 4 km wide stock (the Don Lake Stock) within the Aulneau Batholith. Much of this stock is located south and east of the map area (Blackburn 1981). The various phases of the Don Lake Stock are distinctively magnetic and quartz undersaturated and thus bear more similarity to the Falcon Island Stock (described below) than to the Aulneau Batholith.

The Falcon Island Stock is an oval-shaped pluton about 15 km long by 6 km wide. It is a complex of predominately pink, medium- to coarse-grained, magnetic syenite to alkali syenite in its central, northern, and northwestern portions; and grey, fine- to medium-grained, nonmagnetic monzonite in its southern and eastern portions (Figure 18.2). Coarse-grained, tabular, alkali feldspar phenocrysts, locally aligned in a primary igneous foliation are common in both phases. Isolated bodies of coarse-grained pyroxenite to monzogabbro up to several hundred metres thick grade into or cut the syenitic core. The stock is generally unstrained in the central portions and moderatly foliated at the margins.

A third pluton of unknown dimensions occurs in the southwestern part of the map area. It consists of unrecrystallized, medium-grained granite indicating a post-tectonic origin.

Foliated to massive, biotite-bearing lamprophyre dikes occur throughout the map area. Some of these range in composition from gabbro to pyroxenite which are very similar to those rocks of the Falcon Island Stock.

STRUCTURE, METAMORPHISM, AND ALTERATION

The Falcon Island area has a complex multiphase history of deformation which involves both folding and shearing. Bedding and foliations are generally steeply dipping to vertical. Foliations generally strike northeast, north of the Falcon Island Stock, and strike southeast, south of the stock. Folds are indicated by numerous reversals of top indicators (Figure 18.2) and by minor folds which are commonly tight to isoclinal and steeply plunging. In one locality in the northern part of the map area, a type three interference (Ramsay 1967) of two phases of folding was observed, and in many places two cleavages are visible.

A large first-phase syncline is the predominant structure in the northern map area (Figure 18.2). Facing directions are generally to the northwest, away from the Aulneau Batholith and toward the syncline axis situated south of Bishop Point Island. Several second-phase folds cause local top reversals. South of the Falcon Island Stock, repetition of UDG lithologies and facing directions outline a first-phase syncline trending southeast. However, this also appears to be complicated by overprinting of second-phase folding.

Discrete high-strain zones, as defined by strong schistosity, with or without carbonatization, chloritization, amphibolitization, and sulphidization alteration, occur throughout the map area in minor zones up to 10 m thick. A major deformation zone up to several hundred metres wide trends northeast across the northeastern part of the map area (Figure 18.2). This zone extends to the east for a total length of about 25 km to where it merges with the Pipestone-Cameron Deformation Zone in the Chisholm Island area (Ayer *et al.* 1988). Another deformation zone up to 100 m wide and 5 km long trends north near the contact between the Aulneau Batholith and the Falcon Island Stock.

Amphibolite-facies assemblages occur in supracrustal lithologies throughout most of the map area with the amphibolite-greenschist transition boundary trending easterly across the northern part of the map area (Figure 18.2). In mafic rocks, actinolite porphyroblasts are locally evident on the greenschist-facies side of the boundary and hornblende±garnet porphyroblasts are sporadically present on the amphibolite-facies side. Pelitic sediments may contain garnet, staurolite, andalusite, and/or sillimanite on the amphibolite-facies side of the transition.

Ferromagnesian alteration unrelated to deformation has affected much of the UDG volcanics in the north-central part of the map area. It is most evident in pyroclastic units where much of the fine matrix is replaced by ferromagnesian minerals in crosscutting alteration zones. The alteration varies from intense and pervasive to minor along fractures. This feature was also described by Morrice and MacMaster (1987, 1988) from the Monument Bay area west of the current map area. Within the amphibolite-facies terrane, the alteration assemblage is hornblende±garnet±carbonate. In greenschist-facies terrane, the alteration assemblage is actinolite±chlorite±biotite±carbonate.

ECONOMIC GEOLOGY

The potential for gold mineralization is highest in the northern part of the map area. A northeast-trending shear zone within the Monument Bay area is currently the focus of much exploration activity following the reporting of numerous high gold-assay values by Morrice and MacMaster (1987, 1988). This mineralized trend extends into the UDG in the northwestern part of the Falcon Island area (Figure 18.2). Of about fifty grab samples collected by members of the field party from various gossans and veins from the Falcon Island area, the only two which contain anomalous gold values (greater than 30 ppb gold) are from this area. Both are from small quartz-carbonate veins with minor disseminated sulphides. Sample A contained 290 ppb gold and sample B contained 530 ppb gold (Figure 18.2). All samples were assayed by the Geoscience Laboratory, Ontario Geological Survey.

Another possible area of potential gold mineralization is the deformation zone extending into the northeastern side of the map area from the Chisholm Island area (Figure 18.2). Within the Chisholm Island area this highly strained and altered deformation zone is associated with the Deadbroke Island Gold Occurrence and several anomalous gold assays were discovered from grab samples obtained along its length (Ayer *et al.* 1988).

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19. Project Number 88–14. Geology of the Vista Lake Area, Districts of Rainy River and Kenora

P. Mark Smith and Clive D. Stephenson

Geologists, Precambrian Geology Section, Ontario Geological Survey, Toronto.

INTRODUCTION

Field investigations of the Vista Lake area (Figure 19.1) were initiated in 1988 in order to significantly increase the present geological database, and to stimulate exploration interest in the area. This portion of the Wabigoon Subprovince had been previously examined in the 1880s by A.C. Lawson (1889), and reconnaissance mapping at a scale of 1:63 360 was conducted during 1933 by J.E. Thomson (1934). The adjacent areas to the north, south, and west of the Vista Lake area were mapped by Berger (this volume), Blackburn (1973), and Edwards (1983) respectively.

The Vista Lake area encompasses much of the junction between three septa of greenstone terrane: Manitou–Stormy Lakes greenstone terrane to the northeast, the Pipestone–Cameron–Straw Lakes greenstone terrane to the west, and the Otukamamoan–Pickwick Lakes greenstone terrane to the southeast. A regional shear system (herein termed the Pipestone–Cameron–Manitou Deformation System), transects the northwest portion of the map area, and has been traced for nearly 200 km from the Manitou Lakes area into Lake of the Woods (Berger, this volume; Buck 1986; Buck and Ayer 1987; Edwards 1983). The deformed zone encompasses numerous gold occurrences, including the Cameron Lake Deposit (Buck 1986).

During the summer of 1988, approximately 300 km², bounded by Latitudes 49°01′30″N and by 49°08′30″N and by Longitudes 92°56′15″W and 93°15′00″W, were mapped at a scale of 1:15 840. The centre of the map area lies approximately 75 km south–southwest of Dryden and 55 km north–northeast of Fort Frances. Highway 502 crosses through the eastern portion of the map area, much of which is accessible by logging roads and trails extending from the Cedar Narrows Road (Figure 19.2).

MINERAL EXPLORATION

Unless otherwise stated, the following section has been summarized from the files of the Assessment Files Research Office, Ontario Geological Survey, Toronto.

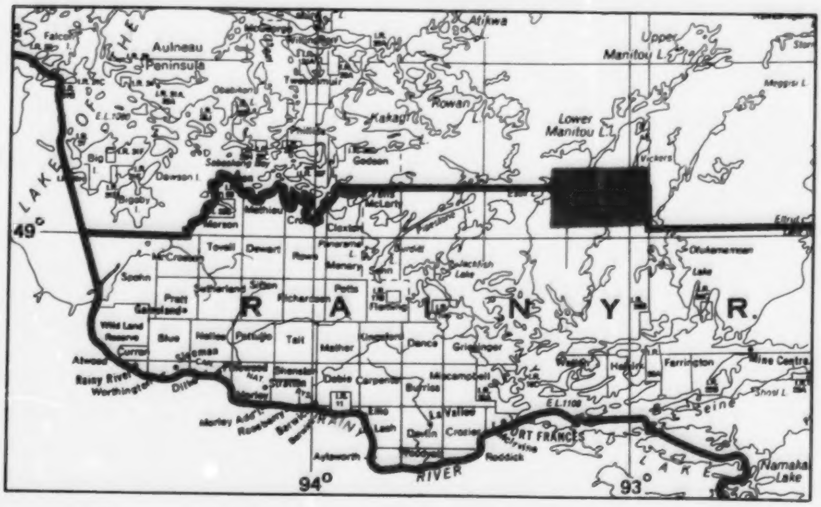
Atikwa
Upper Manitou L.
Falcon I.
Aulneau Peninsula
LAKE OF THE
Meggisi L.
Rowan L.
Kakagi
Lower Manitou L.
Vickers
Big I.
Dawson I.
Bigsby I.
Sabaskong Bay
Godson
McLarty
Mathieu
Morson
Claxton
Croziers
49°
Tovell
Dewart
Rowe
Menary
McCrosson
Spohn
Pratt
Sutherland
Sifton
Richardson
Potts
Fleming
R A I N Y R.
Otukamamoan
Lake
Wild Land Reserve
Blue
Halkirk
Pattullo
Tait
Mather
Kingsford
Dance
Griesinger
Atwood
Curran
Sifton
Rainy River
Worthington
Dilke
Dobie
Carpenter
Burriss
Mccampbell
Ferrington
Mine Centre
Shoal L.
Seine
E.L.1108
Morley
Emo
La Vallee
Devlin
Crozier
FORT FRANCES
Roddick
Aylsworth
94°
RIVER
93°
LAKE
Namakan Lake

Figure 19.1. *Location map for Vista Lake area, districts of Rainy River and Kenora. Scale: 1:1 584 000 or 1 inch to 25 miles.*

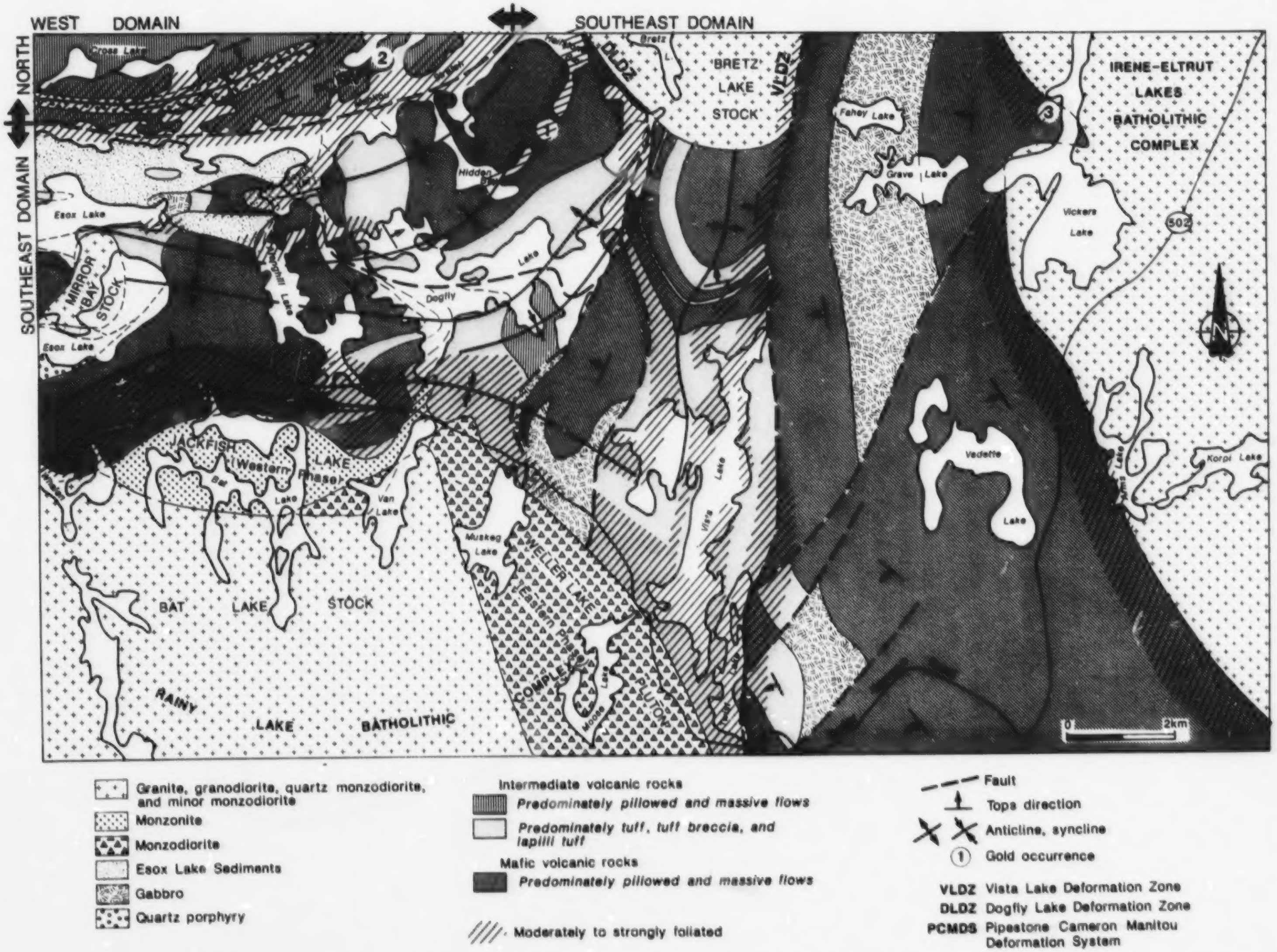
WEST DOMAIN
SOUTHEAST DOMAIN
NORTH
SOUTHEAST DOMAIN
DLDZ
VLDZ
BRETZ LAKE STOCK
IRENE-ELTRUT LAKES BATHOLITHIC COMPLEX
MIRROR BAY STOCK
JACKFISH LAKE (Western Phase)
WELLER LAKE (Eastern Phase) COMPLEX
PLUTON
BAT LAKE STOCK
RAINY LAKE BATHOLITHIC
Cross Lake
Esox Lake
Hidden
Dogfly Lake
Fahey Lake
Grave Lake
Vickers Lake
Vedette Lake
Korpi Lake
Van Lake
Muskeg Lake
Vista Lake
Bar Lake
502
1
2
3
0
2km
N
Granite, granodiorite, quartz monzodiorite, and minor monzodiorite
Monzonite
Monzodiorite
Esox Lake Sediments
Gabbro
Quartz porphyry
Intermediate volcanic rocks
Predominately pillowed and massive flows
Predominately tuff, tuff breccia, and lapilli tuff
Mafic volcanic rocks
Predominately pillowed and massive flows
Moderately to strongly foliated
Fault
Tops direction
Anticline, syncline
Gold occurrence
VLDZ Vista Lake Deformation Zone
DLDZ Dogfly Lake Deformation Zone
PCMDS Pipestone Cameron Manitou Deformation System

Figure 19.2. *Simplified geology of the Vista Lake area. Gold occurrences are indicated numerically on the figure, 1) Sparton Occurrence, 2) Gates Lake Occurrence, 3) Smoothrock Lake Occurrence.*

As of September 8th, 1988, there are 62 claims in good standing within the study area (Mike Hailstone, Staff Geologist, Resident Geologist's Office, Kenora, personal communication, 1988), most of which are near the Manitou Stretch.

Gold with associated molybdenite–chalcopyrite mineralization was first reported near Smoothrock Lake (now known as Vickers Lake) by Parsons (1911), and little exploration work has been done since.

Reconnaissance base–metal exploration was conducted during the late 1960s and early 1970s when Canadian Nickel Company Limited diamond drilled eleven holes. Drill logs indicate mainly graphitic– or pyrrhotite–pyrite–bearing zones were intersected.

Gold exploration has been focused in the Manitou Stretch and Grave Lake–Vickers Lake areas (Figure 19.2). Two main showings have been identified close to Manitou Stretch (Figure 19.2). Between Hailstone and Hidden Bays, southeast of the Manitou Stretch, holes, diamond drilled by Sparton Resources Incorporated, intersected anomalous gold values in a highly carbonatized shear zone with local zones of quartz stockwork. The best intersection assayed 6.19 g/t gold over 0.37 m. At the Gates Lake Occurrence near Gates Lake, gold and antimony values have been reported (Berger, this volume). Only six short diamond drillholes have tested the property, and these were drilled in 1942 when antimony was the target mineral. The Smoothrock Lake Occurrence, west of Vickers Lake (Figure 19.2), was assessed by Northair Mines Limited in 1984. Seven short diamond drillholes tested the mineralized shear zone, and the best drill intersection assayed 13.9 g/t gold over 0.76 m.

GENERAL GEOLOGY

All of the supracrustal and intrusive rocks in the Vista Lake area are interpreted to be Archean in age. The supracrustal rocks have been subject to at least greenschist–facies metamorphism, and henceforth the prefix meta is not used.

The oldest rocks in the area are the volcanic rocks and synvolcanic sills that are locally intercalated with volcanogenic sediments. This succession is unconformably overlain by immature sedimentary rocks in the vicinity of Esox Lake (Figure 19.2). The supracrustal rocks have been intruded by the Rainy Lake Batholithic Complex, the Irene–Eltrut Batholithic Complex (Blackburn 1981), and by two small stocks, herein referred to as the Bretz Lake stock and the Mirror Bay stock (Figure 19.2).

The area is structurally complex, having been subjected to several folding, faulting, and shearing events. The regional-scale Pipestone–Cameron–Manitou deformation system (PCMDS) trends east–northeast through the northwestern portion of the map area (Figure 19.2). As is the case in the Straw Lake area (Edwards 1983), and in the Lower Manitou Lake area (Blackburn 1976), it is not possible to correlate across the PCMDS (*see* Structural Geology). Thus the supracrustal rocks to the northwest and southeast of the deformation system are subdivided below into two distinct domains.

SUPRACRUSTAL ROCKS

Southeast Domain

Much of the area to the southeast of the PCMDS, herein defined as the Southeast Domain (Figure 19.2), is underlain by intermediate and mafic volcanic rocks.

Mafic volcanics comprise massive and pillowed aphyric and feldspar–phyric (leopard rock) mafic flows and sills (Figure 19.2). Feldspar–phyric units (not shown on Figure 19.2) provide excellent marker units that allow fold axes to be accurately defined in the western portion of the domain (Figure 19.2). Mafic volcanic rocks, which occupy the core of the syncline north of Vista Lake and occur north of Dogfly Lake, are locally variolitic and slightly lighter–coloured than those in the south–central, eastern, and western portions of the domain. It is possible that these basaltic rocks are calc–alkalic rather than tholeiitic. Such relationships are critical, as the authors suspect that the rocks exposed in the vicinity of Vista Lake occupy a similar stratigraphic position as those in the Dogfly area, and reflect fault repetition.

Intermediate volcanics rocks comprise flows, tuffs, lapilli tuffs, and tuff breccias. In general, the intermediate rocks are moderately to strongly foliated, and weakly to strongly carbonatized. Extensive accumulations of intermediate flows and pyroclastic rocks, together with minor mafic rocks, occur near Dogfly and Vista lakes (Figure 19.2). Narrower units of intermediate volcanic rock, several of which are shown in Figure 19.2, occur intercalated with the predominantly mafic sequence and can be utilized as additional marker horizons.

In the extreme western portion of the Southeast Domain, a synvolcanic quartz porphyry unit (Figure 19.2) is autobrecciated along its flanks. There has been some discussion as to its genesis, and both intrusive and extrusive models have been suggested (Edwards 1983; Birk 1978).

A thick hornblende–gabbro sill consisting of nematoblastic, ophitic, equigranular, and glomerocrystic phases extends southwards from Fahey Lake (Figure 19.2). Other subvolcanic intrusions comprising discordant gabbro, feldspar–phyric gabbro, quartz gabbro, and peridotite sills, occur near the north end of Dogfly Lake.

Immature wackes and cherts are locally intercalated with both intermediate and mafic volcanic sequences. Sediments also occur along the contacts of, and as inclusions within the hornblende gabbro sill.

Near Esox Lake, the volcanic rocks are unconformably overlain by immature sandstones, siltstones, and mudstones (Figure 19.2). The nature of the thinly bedded to laminated Esox Lake sediments (Edwards 1983) is suggestive of Bouma-cycle turbidites. Windows of the underlying volcanic rock are exposed at numerous locations, and east-trending sediment-volcanic contacts are at a high angle to the volcanic stratigraphy (Figure 19.2). The unconformity with the underlying older sequence is well exposed at several sites on Esox Lake, where clast-supported breccias with a calcareous matrix contain clasts of, and overlie, rusty-weathered, fractured quartz porphyry. The authors interpret these rocks to be paleotalus, thus indicating a high-relief, irregular paleosurface. As these sediments occur only along the southern side of the PCMDS, the authors suspect that they may be the product of fault-scarp erosion.

Northwest Domain

Only a small region of the Northwest Domain, herein defined as the region north of the PCMDS, is exposed in the map area (Figure 19.2). A considerably larger area to the north has been mapped by Berger (this volume). Much of the rock within this domain is highly foliated and altered (cf. Edwards 1983), so that the identification of the protolith must be inferred by extrapolation from adjacent, less-strained lithologies.

Intermediate pillowed and massive flows, intercalated with thick sequences of pillow breccia, lapilli-tuff, and tuff-breccia comprise much of the northwestern domain exposed within the map area (Figure 19.2). These rocks are light coloured, generally carbonatized, and locally the presence of amphibole and plagioclase phenocrysts was noted. Although these rocks have been herein designated as having an intermediate composition, it is possible that much of the domain actually consists of altered calc-alkalic basalt.

An enigmatic, highly foliated, felsic quartz-porphyry unit extends west from Gates Lake south of Cross Lake (Figure 19.2). It was not possible to determine whether the unit was extrusive or intrusive.

SYN- AND LATE-TECTONIC INTRUSIONS

Rainy Lake Batholithic Complex

Within the map area, the Rainy Lake Batholithic Complex comprises northeastern portions of two phases of the Jackfish Lake-Weller Lake Pluton (Blackburn 1981), and the northern portion of a later biotite-granite intrusion, herein defined as the Bat Lake stock.

Jackfish Lake-Weller Lake Pluton

The Jackfish Lake-Weller Lake Pluton is a large diorite-monzonite intrusion which forms a conformable sheet about the northern margin of the Rainy Lake Batholithic Complex (Sutcliffe and Fawcett 1979; Sutcliffe 1980; Blackburn 1981). Within the map area, two phases can be identified, both of which display igneous foliations, locally overprinting tectonic fabrics, and gradational contacts with the supracrustal rocks.

The eastern phase (Figure 19.2) consists of homogeneous, medium-grained monzodiorite which contains abundant xenoliths of volcanic rock along its eastern and northern margins. Many of these xenoliths are partly assimilated.

The western phase (Figure 19.2), which comprises potassium-feldspar-megacrystic monzonite, also contains abundant volcanic xenoliths. The xenoliths have been assimilated to varying degrees, and in many cases have undergone potassium metasomatism. Towards the northern contact, lamprophyric rocks are present; however, it is not clear whether the lamprophyres are intrusive, a phase separation of the alkalic magma, or a highly potassium metasomatized mafic volcanic rock. Dikes of this phase are common within the host volcanic rocks to the north.

The contact between the two phases is exposed near Van Lake, where dikelets of megacrystic monzonite are found within the medium-grained phase.

Bat Lake Stock

Both phases of the Jackfish Lake-Weller Lake Pluton are intruded by the Bat Lake stock (Figure 19.2). Igneous layering is locally developed within the potassium-feldspar megacrystic, biotite granite intrusion, and fine-grained dikes of the granite intrude some distance into the Jackfish Lake-Weller Lake Pluton.

Irene-Eltrut Batholithic Complex

The western phase of the Irene-Eltrut Batholithic Complex, which is exposed in the eastern portion of the study area, consists of homogeneous, medium-grained granodiorite (Figure 19.2). The contact with the supracrustal rocks is sharp, and granodiorite near the contact is generally fine-grained and sheared. In the vicinity of Vickers Lake and Arms Lake, large blocks of mafic volcanics are present as rafts within the intrusion.

Bretz Lake Stock

The Bretz Lake stock is an ovoid intrusion (Figure 19.2), consisting of potassium-feldspar-megacrystic monzodiorite along its southern margin, with quartz content increasing to give quartz monzodiorite and granodiorite towards the north. Xenoliths are fairly common along the intrusion's margins, where a weak igneous foliation parallels the contacts. The intrusion is sheared along the western contact, and sinistral shearing is also evident along the eastern contact north of the map area (*see* Berger, this volume).

Mirror Bay Stock

The Mirror Bay stock is an curved, oblong intrusion (Figure 19.2) of medium-grained granodiorite, within which small mafic xenoliths and aplite dikelets are found locally. The stock intrudes the Esox Lake sediments as well as volcanic rocks. Contacts with the supracrustal rocks are sharp, although several dikes penetrate the supracrustal succession, and one cuts a lamprophyre dike. A weak igneous foliation parallels the contacts but no tectonic fabric was observed within the stock.

STRUCTURAL GEOLOGY

Folds

A regional, north–trending, shallowly plunging syncline is centred on Vista Lake (Figure 19.2). Rocks occupying the core of this fold have a strong, north–trending foliation, and are interpreted to be the youngest volcanic rocks in the Southeast Domain; not withstanding the presence of a contiguous west–facing, fault–bounded block of mafic volcanic rock west of Vista Lake (Figure 19.2).

Easterly trending, steeply plunging folds dominate the western half of the map area (Figure 19.2). These are accompanied by the development of an easterly trending, axial–planar foliation which increases in intensity towards the batholith. Towards the east, the fold axes flex northward, becoming approximately parallel to the eastern shore of Dogfly Lake. In this vicinity, earlier foliations are folded, and folds are non–cylindrical with shallow–plunging lineations which diverge on opposing limbs. Such folds may represent sheath folds.

Smaller–scale folds (not shown on Figure 19.2) occur as parasitic folds to larger–scale folds, but are also common within shear zones. Facing reversals in the Esox Lake sediments are common and abrupt and do not appear continuous with those within the underlying volcanic rocks. On closer examination many of these reflect tight, low–amplitude, "S" or "Z" folds.

Deformation Zones

The most prominent structural element in the map area is the Pipestone–Cameron–Manitou Deformation System which subdivides the Vista Lake area into two separate structural–stratigraphic domains (Figure 19.2). A distinct "break" follows the Manitou Stretch; however, the shear system is also characterized by numerous, sub–parallel, discrete shear zones separated by lithons of relatively undeformed volcanic rocks. Splays extending from the main deformation zone extend southwest through Hailstone and South bays. Foliations and lineations are subvertical within the main deformation zone, indicative of vertical strain. Drag folds express north–side–up displacement within sheared Esox Lake sediments, and are consistent with these lineations. Most of the rocks in the northwest domain are highly foliated and may be included as part of the deformation system. The curvilinear nature of the PCMDS is roughly parallel to the southern margin of the Atikwa Lake Batholith, located north of the map area, throughout most of its strike length.

Two northerly trending, deformed zones, the Vista Lake Deformation Zone (VLDZ) and the Dogfly Lake Deformation Zone (DLDZ), extend north from Vista Lake and diverge about the Bretz Lake stock (Figure 19.2). It should be noted that these are not necessarily simple shear zones. The discontinuous, anastomosing, deformed zones consist of highly stretched and strongly foliated volcanic rocks, but they occur along the limbs of a major syncline, and much of this strain could be attributed to that folding. Lineations within the deformed zones are relatively shallow and several small–scale kinematic indicators record sinistral shear within the VLDZ. The Bretz Lake stock has apparently been subjected to sinistal shear within an extension of the VLDZ north of the study area (*see* Berger, this volume). The western margin of the stock is also sheared, but kinematics were not determined.

A contact–strain aureole extends more than 2 km out from the Rainy Lake Batholithic Complex and is a deformation zone in its own right. Rocks within that domain are moderately to highly foliated, and stretched fragments are rod–like and subvertical near the intrusion's margins. The contact aureole surrounding the Irene–Eltrut Batholithic Complex is much less impressive, extending only several hundred metres.

Numerous smaller shear zones are located throughout the map area, and many of these parallel lithological contacts.

Faults

Within the Southeast Domain, interpreted faults (Figure 19.2) trend slightly oblique to lithological contacts and define the margins of lithologically and structurally distinct blocks. In most cases neither the amount nor the direction of offset is evident, although within an area of low strain near Vedette Lake, apparent horizontal displacement is indicated (Figure 19.2). Such structural sub–domains make stratigraphic correlation tenuous.

ALTERATION AND METAMORPHISM

All of the supracrustal rocks in the map area have been subject to at least greenschist–facies metamorphism. Rocks adjacent to the syn– and late–tectonic intrusions have been metamorphosed to amphibolite facies, and subsequently weakly to strongly epidotized. About the smaller stocks, and the Irene–Eltrut Batholithic Complex, the amphibolite facies aureole is narrow, extending less than 1 km into the supracrustal rocks, while along the margins of the

Jackfish Lake–Weller Lake Pluton the amphibolite facies contact aureole extends more than 2 km into the surrounding rocks.

Much of the intermediate volcanic rocks in the area are carbonatized, and calcite is the dominant mineral phase. Intense ferroan carbonate alteration, localized along the PCMDS, encompasses regions of known gold mineralization.

ECONOMIC GEOLOGY

The authors believe several areas represent potential targets for gold exploration.

The silicified and carbonatized arsenopyrite–pyrite– stibnite–bearing Gates Lake Occurrence near Gates Lake warrants additional work, particularly as Sparton Resources Incorporated intersected a gold–bearing shear system along strike over 1 km to the northeast in Peep Bay (*see* Berger, this volume). The association of antimony and gold is indicated in numerous deposits (Colvine *et al.* 1988), and may prove to be a useful pathfinder element in the Manitou Stretch area. Further exploration work may also be warranted on the Sparton Resources Incorporated arsenopyrite–pyrite–gold–bearing occurrence in the Hailstone and Hidden Bay area, although considerable drilling has been done to date.

Numerous small molybdendite– and chalcopyrite–bearing quartz veins were noted in the vicinity of Grave and Fahey lakes during the field season. Quartz vein samples taken to the north of the map area (Berger, this volume) returned highly anomalous gold values. These, combined with the presence of known gold mineralization at the Smoothrock Lake Occurrence, indicate the Fahey–Grave–Vickers Lakes area has potential for gold mineralization.

The DLDZ and the VLDZ present untested potential gold exploration targets. Indeed, a highly silicified segment of the Dogfly Lake Deformation zone crops out between Vista Lake and Dogfly Lake. This material was sampled by the field party but analyses are still pending.

Shear zones developed in regions of differential strain along the margins of folded discordant mafic and ultramafic sills present potential gold targets (Colvine *et al.* 1988). Fold noses and boudinaged portions of a discordant ultramafic sill in the Dogfly Lake area (Figure 19.2) are highly sheared and carbonatized, with abundant quartz veins throughout. However, the analysis of several samples of quartz and its carbonatized host rock taken by the field party returned a maximum of 14 ppb gold. The authors were later informed that numerous samples taken earlier by Mike Hailstone (Staff Geologist, Resident Geologist's Office, Kenora, personal communications, 1988) returned no more than 6 ppb gold.

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20. Project Number 88–15. Geology of the Manitou Stretch Area, District of Kenora

Ben Berger

Geologist, Precambrian Geology Section, Ontario Geological Survey, Toronto.

INTRODUCTION

The Manitou Stretch area was mapped to improve the geological data base, thereby assisting in the exploration for precious– and base–metal mineralization. Mapping successfully subdivided the supracrustal lithologies into litho–stratigraphic groups; defined the major structural elements and recognized environments favourable to economic mineralization.

Gold is known to occur in five showings in the map area. Although many assays are still pending, a selected grab sample collected by the field crew from a quartz vein at the Gold Standard Occurrence on Neilson Lake and analyzed by the Geoscience Laboratories, Ontario Geological Survey, Toronto, returned 1.37 ounces gold per ton, 0.85 ounce silver per ton, and 1.5 percent copper.

The Manitou Stretch area is part of the Wabigoon Subprovince and lies within the Manitou Lakes greenstone belt near the junction with the Pipestone–Cameron Lakes greenstone belt. The map area area is bounded between Latitudes 49°08′30″N and 49°15′00″N and Longitudes 92°56′15″W and 93°15′00″W. Approximately 300 km² (*see* Figure 20.1) was mapped at 1:15 840 scale during the 1988 field season. The map area is contiguous with the Vista Lake area to the south mapped by Smith and Stephenson (this volume). The Manitou Stretch area adjoins areas previously mapped by Blackburn (1973) to the northeast and by Edwards and Sutcliffe (1977) to the west. The area was previously mapped at 1:63 360 scale by Thomson (1934).

The map area can be reached by boat from the Cedar Narrows logging road (10 km south) via Esox Lake and the Manitou Stretch (cf. Smith and Stephenson, this volume). Alternatively, aircraft based in Fort Frances (43 km south) or Nestor Falls (45 km west) provide access to the area. Within the map area, numerous maintained portages provide boat access to many lakes; however, aircraft–supported fly camps were used to map the Harris Lake and Kahabeness Lake areas.

MINERAL EXPLORATION

Thomson (1934) reported that gold exploration in the early 1900s resulted in discovery of the Gold Standard Occurrence on Neilson Lake. Here, a 95–foot (28.9 m) shaft with 110 feet (33.5 m) of drifting was excavated to explore a gold–chalcopyrite–bearing quartz vein. One assay of 1.8 ounces gold per ton is reported from the mine dump (Beard and Garratt 1976). In the 1930s and 1940s, gold was discovered west of the map area at Straw Lake and within the map area at Gates Lake in association with stibnite, arsenopyrite, and pyrite in sheared

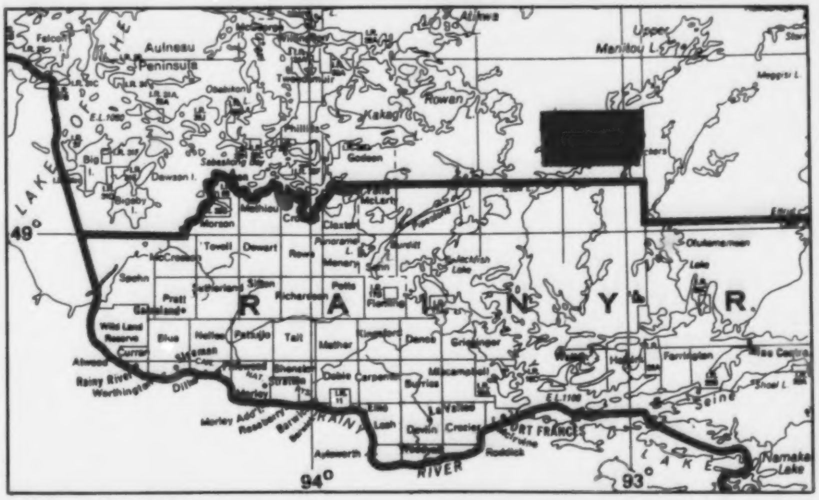

Figure 20.1. *Location map for the Manitou Stretch Area, District of Kenora. Scale: 1:1 584 000 or 1 inch to 25 miles.*

metavolcanics. At the Gates Lake Occurrence, which also includes the Peep Bay showing, visible gold in quartz veins and assays up to 0.36 ounce gold per ton and 7 percent antimony (Beard and Garratt 1976; Resident Geologist's Files, Ministry of Northern Development and Mines, Kenora) were reported.

Recent exploration for gold by Sparton Resources Incorporated and Jalna Resources Incorporated has concentrated on the Gates Lake–Peep Bay area and at Aronson Lake; however, economic deposits have not yet been discovered.

A number of mining claims are currently in good standing in the Manitou Stretch area; however, no major exploration has occurred since 1985.

GENERAL GEOLOGY

The map area is underlain by Archean supracrustal rocks composed of mafic, intermediate, and felsic metavolcanics, related intrusive rocks and metasediments which have been intruded by Archean granitoid stocks and batholiths (Figure 20.2). The metavolcanics were subdivided into litho–stratigraphic groups based on composition and morphology, which were then tentatively correlated with metavolcanic groups described by Blackburn (1982, 1976) and by Edwards (1983).

Mafic metavolcanics interlayered with laminated chert, siltstone, and intermediate pyroclastics form a continuous group along the southeastern side of Lower Manitou Lake, the entire eastern side, and part of the western side of the Manitou Stretch. The mafic rocks comprise massive, pillowed, and plagioclase–phyric ("leopard rock") flows with minor hyaloclastite and mafic dikes. Pillows are generally well formed, closely packed, and non–vesiculated with narrow rims and very little inter–pillow material. White anhedral plagioclase phenocrysts from 0.5 to 5 cm in size and from 5 to 50 percent volume are common in flows in several areas, and extensive sequences occur south of Kahabeness Lake. These rocks are correlative with the Glass Bay Formation of the Wapageisi Group (Blackburn 1982, 1976).

White chert beds and laminae, cherty siltstone and intermediate tuff and lapilli tuff are interlayered with the mafic metavolcanics of the Glass Bay Formation and form laterally extensive units several kilometres long and up to 300 m thick. Based on lithologic descriptions and lateral continuity with similar units to the northeast, these rocks are cor-

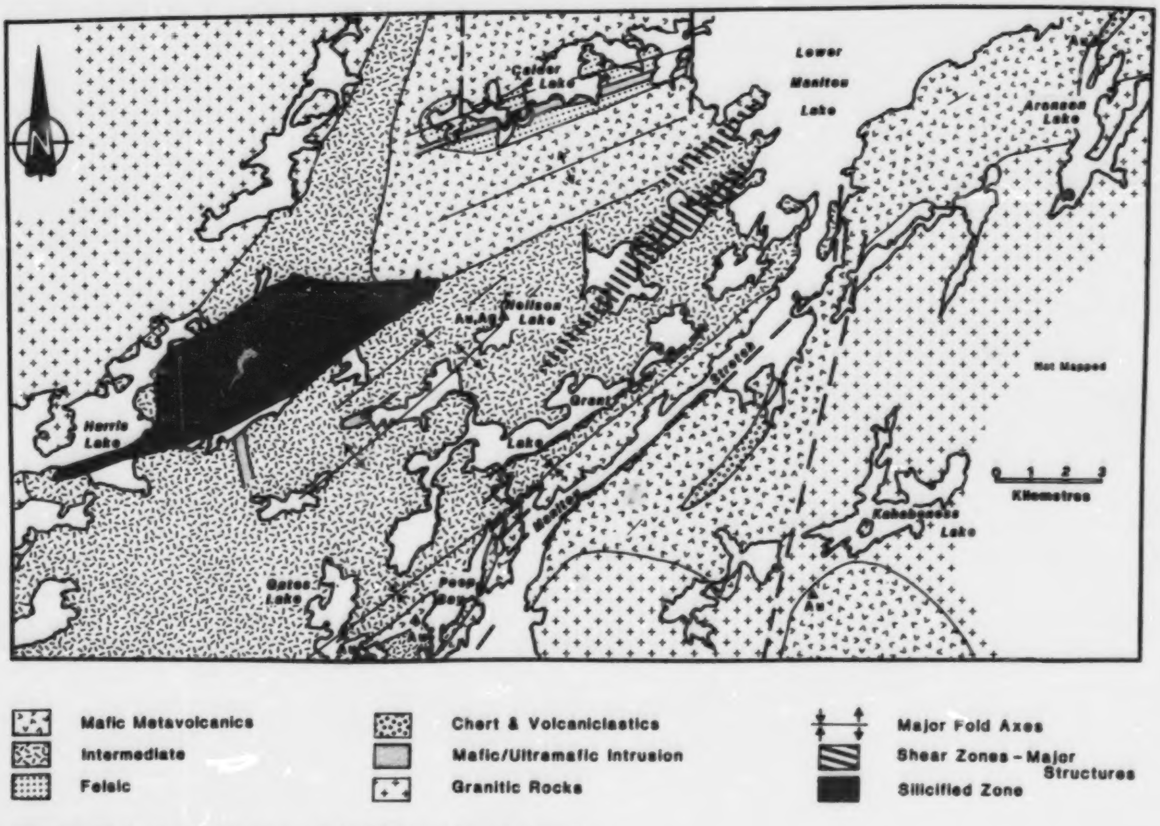
N
Calder Lake
Lower Manitou Lake
Aronson Lake
Au
Nelson Lake
Au,Ag
Grant Lake
Stretch
Manitou
Harris Lake
Gates Lake
Peep Bay
Au
Not Mapped
0 1 2 3
Kilometres
Kahabeness Lake
Au
Mafic Metavolcanics
Intermediate
Felsic
Chert & Volcaniclastics
Mafic/Ultramafic Intrusion
Granitic Rocks
Major Fold Axes
Shear Zones – Major Structures
Silicified Zone

Figure 20.2. *General geology of the Manitou Stretch Area.*

relative with the Etta Lake Formation of the Wapageisi Group (Blackburn 1982, 1976).

Mafic metavolcanics immediately west of Lower Manitou Lake along the northern boundary of the map area are composed of massive, medium-grained to gabbroic textured flows with minor plagioclase-phyric flows and mafic to intermediate pillowed and pillow brecciated flows. These rocks are tentitively correlated with the Pincher Lake Group (Blackburn 1982, 1976).

Intermediate to felsic rocks in the Calder Lake area overlie the mafic rocks described above and are composed of massive to well-bedded pyroclastic and epiclastic deposits, some of which are interpreted by the author to have been deposited by ash flows. They are correlative with the Upper Manitou Lake Group (C.E. Blackburn, Resident Geologist, Ministry of Northern Development and Mines, Kenora, personal communication, 1988).

Intermediate to mafic flows and fragmentals comprise a distinctive rock group which underlies the southwest, central, and north-central part of the map area (Figure 20.2). Among the characteristic features which permit easy field identification of these rocks are large, in places over 3 m, pillows with thick interpillow material (5 cm plus), abundant and large (up to 5 cm) vesicles and gas cavities and prominent amphibole and plagioclase phenocrysts. Fragmental units composed of pillow breccia and pillow breccia mixed with pyroclastic material are commonly interlayered with the flows and form up to 100 m thick deposits in the Grant Lake area (Figure 20.2). These rocks are contiguous with intermediate, calc-alkalic metavolcanics described by Edwards (1983) west of the map area, and are morphologically similar to calc-alkalic metavolcanics described by Berger (1987) in the Sandybeach Lake area and by Morrice and MacMaster (1987) in the Lake of the Woods area.

The supracrustal rocks are intruded by mafic to ultramafic sills and dikes. A gabbroic sill on Calder Lake is intrepreted by the author to be synvolcanic, whereas a pyroxenitic dike on Harris Lake appears to be post to late syntectonic in origin.

The supracrustal rocks are intruded by three Archean granitoid intrusions. A late syntectonic to post tectonic tonalitic to granodioritic phase of the Irene-Eltrut Lakes Batholithic Complex intrudes along the eastern boundary of the supracrustal rocks (Figure 20.2). Monzonitic to granodioritic rocks of the Bretz Lake late syntectonic to post tectonic stock intrude along the southern part of the map area and extend into the Vista Lake area (*see* Smith and Stephenson, this volume). A part of the Lawrence Lake Batholith intrudes the supracrustal rocks along the northwestern boundary of the map area and is composed of tonalite, quartz diorite, diorite, and migmatite. This intrusion is syntectonic and is commonly foliated and locally sheared.

STRUCTURE AND METAMORPHISM

The major structural feature in the map area is a northeast-trending shear zone system that extends from the northeast through the Grant Lake-Manitou Stretch area to the Gates Lake area (Figure 20.2). This system is composed of several discreet, subparallel shear zones, each of which is characterized by a predominant vertical component and a late stage sinistral component of movement. The shear zone system is a regional feature extending to the northeast (Manitou Straits Fault, Blackburn 1982, 1976) and to the west of the map area (Pipestone-Manitou Stretch Fault, Edwards 1983). Smith and Stephenson (this volume) refer to the latter fault as the Pipestone-Cameron-Manitou deformation system and indicate that movement was predominantly vertical. The shear zone system divides the map area into western and eastern structural domains.

West of the shear zone system, numerous reversals in stratigraphic facings define several northeast-trending fold axes and indicate that stratigraphy is not homoclinal. In several places, the northeast structures were observed to sinistrally rotate and locally transpose an earlier formed fabric. This earlier fabric is east-northeast-trending and is subparallel to bedding.

East of the shear zone system, northeast-trending structures predominate and are subparallel to stratigraphy which is generally northwest facing. Folding only occurs near the contact with the Irene-Eltrut Lakes Batholithic Complex. The east-northeast-trending structures observed in the western structural domain are either poorly preserved or absent in this eastern domain.

Within the shear zone system, stratigraphy is commonly transposed and sinistrally rotated to the extent that correlation between the two domains is uncertain. Stratigraphic correlation is further complicated by late stage north- to northwest-trending faults which sinistrally offset earlier structures, the supracrustal rocks, and the granitoid intrusions.

The supracrustal rocks have attained lower to middle greenschist facies metamorphism as indicated by the development of chlorite, epidote, and actinolite in the metavolcanics. Amphibolite facies metamorphic aureoles are developed around the granitoid intrusions as indicated by the development of hornblende and biotite in the metavolcanics. A narrow, up to 500 m wide, amphibolite aureole occurs around the Irene-Eltrut Lakes intrusion and the Bretz Lake Stock. The "granite-greenstone" contact is abrupt and well defined around both of these intrusions. An amphibolite aureole up to 2 km is developed around the Lawrence Lake Batholith, and there is a gradational contact with the supracrustal rocks.

ECONOMIC GEOLOGY

There is good potential for gold and fair to poor potential for base–metal mineralization in the map area. At the Gates Lake and Peep Bay (Figure 20.2) showings, gold is associated with pyrite, arsenopyrite, and stibnite in quartz veins, and in silicified and carbonatized zones in sheared mafic metavolcanics. Gold values up to 0.4 ounce per ton over about 1 m are reported by previous workers (Resident Geologist's Files, Ministry of Northern Development and Mines, Kenora), and mineralization is open along strike at both showings. Both showings occur within the northeast–trending shear zone system, yet at both showings mineralization appears more closely associated with east–northeast structures. This area is considered by the author to be a highly favourable exploration target.

The Gold Standard Occurrence on Neilson Lake (Figure 20.2) contains gold in a pyritic and chalcopyritic quartz vein. The northeast–striking vein is up to 2 m wide, boudinaged, and pinches out along strike. The vein is hosted by deformed intermediate metavolcanics; however, shearing is not evident. Gold values up to 1.8 ounces per ton were reported (Beard and Garratt 1984) from the sulphide–bearing phase of the vein. Quartz and carbonate veins were observed by the author along strike on the northern shore of Napanee Lake 2.8 km southwest of the Gold Standard Occurrence, which indicates this entire area is a potential exploration target.

On the northern shore of Aronson Lake (Figure 20.2), trenches sunk by Jalna Resources Incorporated (Resident Geologist's Files, Ministry of Northern Development and Mines, Kenora) in graphitic and pyritic cherty beds of the Etta Lake Formation were discovered and sampled by the author. Gold has not previously been reported from these rocks; however, one grab sample collected by the author returned 730 ppb gold and 2 ppm silver over 30 cm from sheared and pyritic chert. There appears to be potential for economic gold mineralization in this environment.

South of Kahabeness Lake, pyritic and chalcopyritic quartz pods hosted by amphibolitized mafic metavolcanics were discovered and sampled by the field crew. An assay of 685 ppb gold and 2 ppm silver was returned from one sample, which indicates this area warrants further prospecting. This part of the map area is contiguous with the Fahey–Grave lakes area where auriferous chalcopyrite–molybdenite quartz veins were previously discovered (Smith and Stephenson, this volume).

Previous unsuccessful base–metal exploration appears to have concentrated on testing the potential of parts of the Etta Lake chert–epiclastic formation and parts of the mafic metavolcanics correlative with the Pincher Lake Group (Resident Geologist's Files, Ministry of Northern Development and Mines, Kenora). Although there may still be targets here, it appears these rocks have low economic potential.

The felsic–intermediate metavolcanics in the Calder area are untested, and mapping indicates that hydrothermally altered and fuchsitic rocks are present. Another potential gold–base metal target occurs in the Harris Lake area where intermediate pyroclastic deposits on a number of the islands and part of the mainland are partly to totally silicified. The silicified zone is extensive and in a few places disseminated pyrite and pyrrhotite were observed.

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21. Project 88–7. Reconnaissance Investigations of Granitoid Rocks in the Wabigoon Subprovince

G.P. Beakhouse

Geologist, Precambrian Geology Section, Ontario Geological Survey, Toronto.

INTRODUCTION

Approximately one month in the summer of 1988 was devoted to reconnaissance investigations of granitoid rocks in the western Wabigoon Subprovince (Figure 21.1). The results of this investigation will be incorporated in the maps and reports of the Geology of Ontario project and will be used to plan future projects. For the most part, previously published maps were used for geological control and emphasis was placed on collecting samples for geochemical analysis. The objectives of the geochemical study were to identify similarities and differences between various plutons and plutonic complexes, and to evaluate the significance of these with respect to models of their origins. The results will eventually lead to a better understanding of plutonism and its significance for tectonic history and mineralization environments of the Wabigoon Subprovince.

The investigations concentrated on plutons from two different settings; the Wabigoon Diapiric Axis in the vicinity of the towns of Ignace, Upsala, and Atikokan, and two western Wabigoon granitoid complexes, the Aulneau and Atikwa batholiths, south of

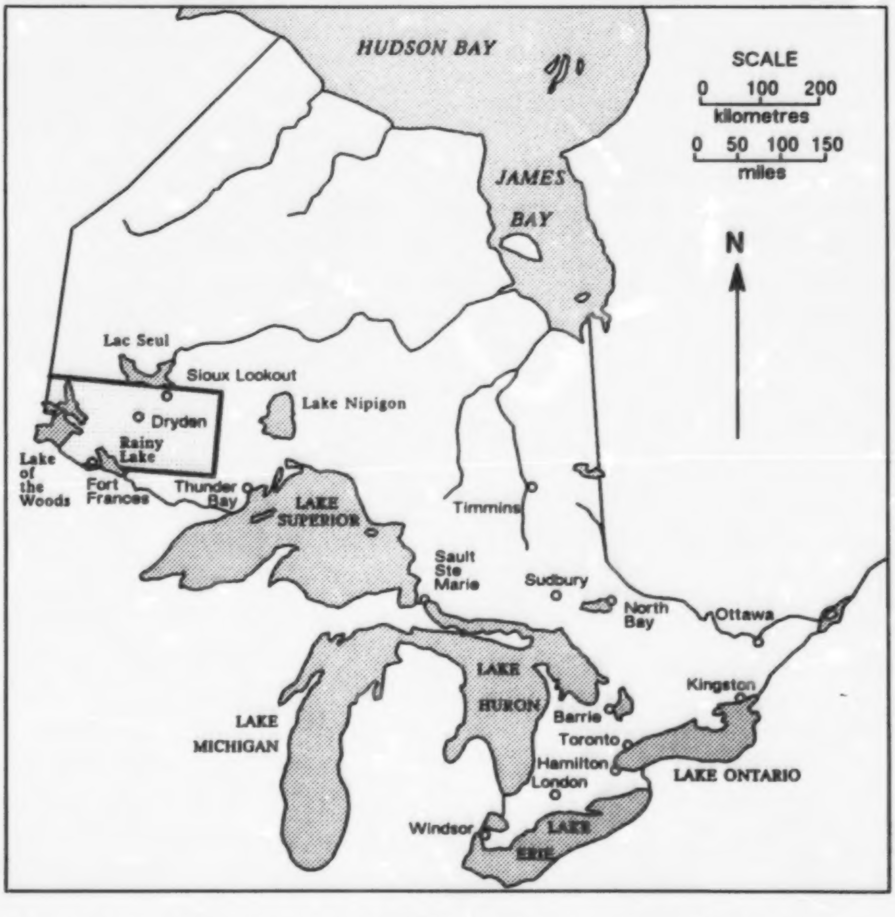
HUDSON BAY
JAMES BAY
SCALE
0 100 200
kilometres
0 50 100 150
miles
N
Lac Seul
Sioux Lookout
Dryden
Lake Nipigon
Rainy Lake
Lake of the Woods
Fort Frances
Thunder Bay
LAKE SUPERIOR
Timmins
Sault Ste Marie
Sudbury
North Bay
Ottawa
Kingston
LAKE HURON
LAKE MICHIGAN
Barrie
Toronto
Hamilton
London
LAKE ONTARIO
Windsor
LAKE ERIE

Figure 21.1. *Location map of the western part of the Wabigoon Subprovince, Northwestern Ontario.*

the towns of Kenora and Dryden, respectively (Figure 21.2).

THE WABIGOON DIAPIRIC AXIS

The western and eastern parts of the Wabigoon Subprovince are separated by an areally extensive granitoid terrane that has been referred to as the Wabigoon Diapiric Axis (hereafter referred to as WDA; Edwards and Sutcliffe 1980). This area consists primarily of foliated to gneissic tonalite together with foliated to massive granodiorite to granite (Percival 1987a, 1987b, 1987c, 1987d). Metavolcanic rocks underlie less than ten percent of the WDA, and occur as thin, predominantly mafic septa and, less commonly, as thicker, more heterolithic belts (e.g. Lumby Lake; Jackson 1982, 1983).

The U–Pb zircon concordia intercept and $^{207}Pb/^{206}Pb$ ages for the Marmion Lake Granitoid Complex and adjacent Lumby Lake Greenstone Belt range from 2929 to 2999 Ma, indicating that at least some of the plutonic and metavolcanic rocks in the WDA are significantly older than those occurring in the Western Wabigoon Subprovince (Davis and Jackson 1985). These results, together with certain field evidence have led to the interpretation of the WDA as 3 Ga basement complex abutting against a 2.7 to 2.75 Ga volcano–plutonic assemblage in the western Wabigoon Subprovince (Thurston and Davis 1985; Wilks *et al.* 1986). This interpretation is analogous in many respects to that made for the Winnipeg River Subprovince which lies to the north of the western Wabigoon Subprovince and is characterized by older (2.83 to 3.16 Ga) tonalitic rocks and younger (2.65 to 2.7 Ga) granodioritic to granitic plutons (Beakhouse 1985; Corfu 1988). The younger plutons in the Winnipeg River Subprovince have a distinctive geochemical and isotopic character (high large ion lithophile elements (LILE) and yttrium, low calcium, and elevated initial strontium isotope ratios) relative to western Wabigoon plutonic rocks which suggests that the former are products of the partial fusion of the older tonalites (Beakhouse 1983; Beakhouse and McNutt 1986). The sampling of granitoid rocks from the WDA was designed to test this analogy and further evaluate the involvement and extent of older crust in the evolution of the WDA.

Field observations made during the course of this reconnaissance were consistent with existing geological mapping in the area (Percival 1987a, 1987b, 1987c, 1987d). Foliated to gneissic tonalitic rocks are intruded by elliptical to irregularly shaped granodioritic to granitic plutons. Development of gneissic fabrics in the tonalitic rocks is commonly spatially associated with amphibolites derived from mafic metavolcanic rocks that occur as laterally continuous narrow belts or septa, or in inclusion–rich zones that are concordant to the gneissic stratigraphy. The development of gneissosity is interpreted to be a consequence of deformation in lithologically heterogeneous zones accompanied by an aqueous fluid phase that promoted metamorphic differentiation and local partial melting in these zones. The fluid phase may be concentrated in these zones either because it was derived *in situ* through dehydration reactions in the mafic metavolcanic rocks or because heterogeneous deformation enhanced porosity that focused fluid migration from depth.

Mafic dikes within tonalites have been reported from the Marmion Lake tonalite in the Lumby Lake area (Jackson 1983). During this investigation, mafic dikes were encountered further to the east in the same plutonic complex in the vicinity of the town of Upsala, but were not seen elsewhere in the WDA.

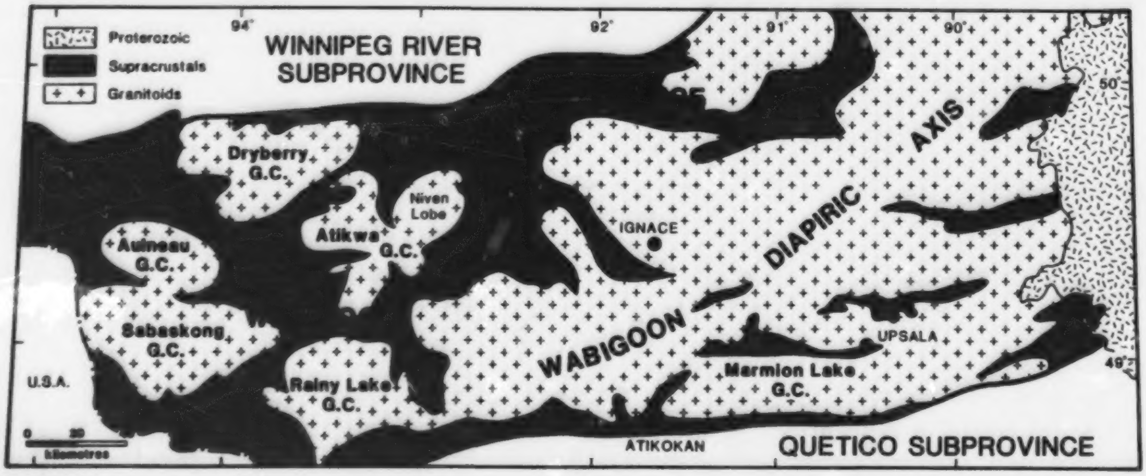

Figure 21.2. *Geological compilation map of a portion of the Wabigoon Subprovince illustrating the location of granitoid complexes (G.C.) discussed in the text.*

Plutons intruding the tonalites are predominantly of granodioritic composition, although some of the smaller plutons are granitic or syenitic. Microcline megacrysts are very common in granodioritic phases. These rocks typically are massive to weakly foliated.

WESTERN WABIGOON GRANITOID COMPLEXES

The Aulneau and Atikwa granitoid complexes which lie within the western Wabigoon Subprovince were briefly examined and sampled. The former was mapped by Ziehlke (1974). Most of the northeastern lobe of the Atikwa Batholith has been mapped by the author at a scale of 1:50 000. This mapping indicates that both complexes contain similar lithologies although their proportions differ.

Massive to foliated to gneissic tonalites and granodiorites that megascopically resemble those in the WDA are the predominant rock types. Two other lithologic associations also characterize these batholiths; marginal intermediate to mafic to ultramafic intrusions, and fine–grained dikes. These associations are present in both the Aulneau and Atikwa batholiths, but are more common in the latter.

The marginal intermediate to ultramafic intrusions include: a) quartz dioritic to gabbroic complexes that are gradational into tonalitic phases, and appear to be integral parts of the batholiths; and b) discrete mafic to ultramafic intrusions. The former are commonly full of mafic to ultramafic clots and are extremely heterogeneous. Much of the internal variability within the quartz dioritic to gabbroic complexes is provisionally attributed to magma mixing (*see* also Davis and Edwards 1985). The discrete mafic to ultramafic intrusions may be the unmixed, mafic end member involved in the association discussed above.

Fine–grained, aphyric to porphyritic, mafic to felsic dike phases are common in the Niven Lobe of the Atikwa Batholith, especially near the eastern contact and several dikes were also noted during the brief examination of the Aulneau Batholith. At one location in the Atikwa Batholith, an intermediate dike was observed to have adjacent, compositionally and texturally similar, pillow shaped pods suggesting that some of the medium–grained phases of the batholith were partially molten at the time of dike emplacement.

Available high precision U–Pb geochronology indicates that these batholiths are coeval with the metavolcanic rocks that surround them (Davis *et al.* 1982; Davis and Edwards 1986) and, at least in the case of the Atikwa Batholith, with mafic intrusions along their margins (Morrison *et al.* 1985). The abundance of dikes in the eastern portion of the Niven Lobe of the Atikwa Batholith suggests that the present erosional level exposes a comparatively shallow, oblique section through a subvolcanic plutonic complex.

SUMMARY

Observations made during the course of this investigation are consistent with the interpretation that some of the large granitoid complexes occurring within the western Wabigoon Subprovince represent subvolcanic magma chambers. No field evidence (e.g. mafic dikes, unconformities) was encountered to suggest that the antiquity of the Marmion Lake Granitoid Complex can be applied to the WDA as a whole. Planned geochemical and isotopic studies will address this problem further.

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22. Project Number 86–43. Geological Synopsis in the Dinorwic–Sioux Lookout Area—The Sandybeach Lake Area, Northwestern Ontario

Lesley Chorlton

Geologist, Precambrian Geology Section, Ontario Geological Survey, Toronto.

INTRODUCTION

In 1986, the Ontario Geological Survey initiated a three-year synoptic program in the Dinorwic–Sioux Lookout area. The project included geological mapping (Berger 1986, 1987, 1988; Berger *et al.* 1987a, 1987b, 1987c, 1988a, 1988b) and regional mineral deposit and structural studies (Chorlton 1986, 1987). During the summer of 1988, an investigation of the tectonic history, the detailed mapping of an ironstone marker horizon, and the study of several gold occurrences were concluded in the Sandybeach Lake area (Figure 22.1). This publication reports on the preliminary results of the 1988 field season.

The Sandybeach Lake area is approximately 35 km northeast of Dryden and 35 km southwest of Sioux Lookout, and covers adjacent segments of Webb, Laval, Hartman, Echo, McAree, McFie, and Pickerel townships. Parts of the area were first mapped by Hurst (1932) and Satterly (1941), followed by Armstrong (1951), Johnstone (1969), Breaks *et al.* (1976), and Page and Christie (1980). McAree, McFie, Laval, and Hartman townships have recently been remapped (Berger *et al.* 1987a, 1987b, 1987c, 1988a, 1988b; Berger 1986, 1987, 1988).

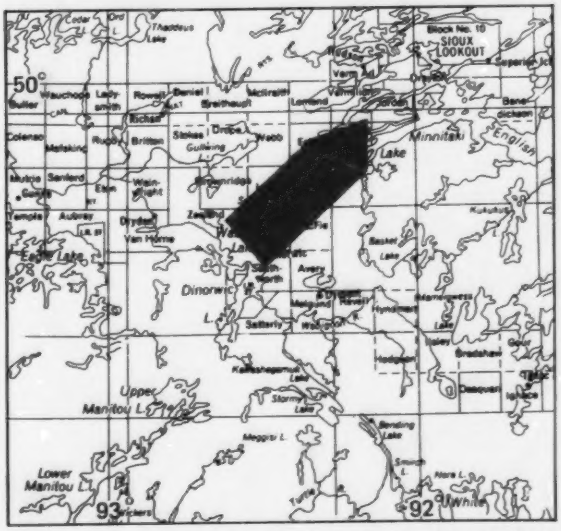
50°
Cedar L.
Ord L.
Thaddeus Lake
Block No. 10
SIOUX LOOKOUT
Superior Jct
Vermilion
Wauchope
Lady-smith
Rowell
Daniel
Breithaupt
McIlraith
Lomond
Bene-dickson
Richan
Colenso
Melgund
Rugby
Britton
Stokes
Drope
Gullwing L.
Webb
Minnitaki
Lake
English
Mutrie
Sanford
Eton
Wain-wright
Temple
Aubrey
Dryden
Zealand
Van Horne
Eagle Lake
McFie
Basket Lake
Kukukus
Smith-worth
Avery
Dinorwic L.
Hyndman
Satterly
Lake
Bradshaw
Hodgson
Kaweshegamuk Lake
Davis
Upper Manitou L.
Stormy Lake
Ignace
Bending Lake
Meggisi L.
Smoke L.
Hare L.
Lower Manitou L.
93°
92°
White

Figure 22.1. *Location map for the Sandybeach Lake Area, Northwestern Ontario. Scale: 1:1 584 000 or 1 inch to 25 miles.*

The current project involved 1:15 840 scale mapping of the area north and west of Sandybeach Lake and more detailed mapping of gold occurrences (Chorlton 1986, 1987). Gold occurrences east of the Sandybeach Lake were investigated during the 1988 field season. The remainder of the season was devoted primarily to investigating the regional structure and its effect on the map pattern over a broader area. Since the stratigraphic relationship between the Minnitaki and Neepawa groups has been the subject of controversy (Johnstone 1969; Trowell *et al.* 1980), the relationship of an ironstone marker unit above the basal contact of the predominantly metasedimentary Minnitaki Group with the local Neepawa Group metavolcanic substratum was also studied.

For more complete descriptions of the regional geology, the reader is referred to Berger (1987) and Chorlton (1987).

GOLD MINERALIZATION EAST OF SANDYBEACH LAKE

GENERAL GEOLOGICAL SETTING

The Alto–Gardnar, Midas, Rivers, Schmidt, and Glatz occurrences (Figure 22.2) are hosted by part of the Southern Metavolcanic Belt (Trowell *et al.* 1980). This terrane is traversed by several discrete, northeasterly striking, steeply to moderately dipping shear zones. One of these shear zones, stretching for over 40 km northeast from the southeastern corner of Sandybeach Lake, forms a tectonic contact between the Southern Metavolcanic Belt and the Minnitaki Group. The main sense of movement on this shear zone is sinistral with a southeast-side-up vertical component, as determined from displacement

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This project A.3.1 is part of the five year Canada–Ontario 1985 Mineral Development Agreement (COMDA), a subsidiary agreement to the Economic and Regional Development Agreement (ERDA) signed by the governments of Canada and Ontario.

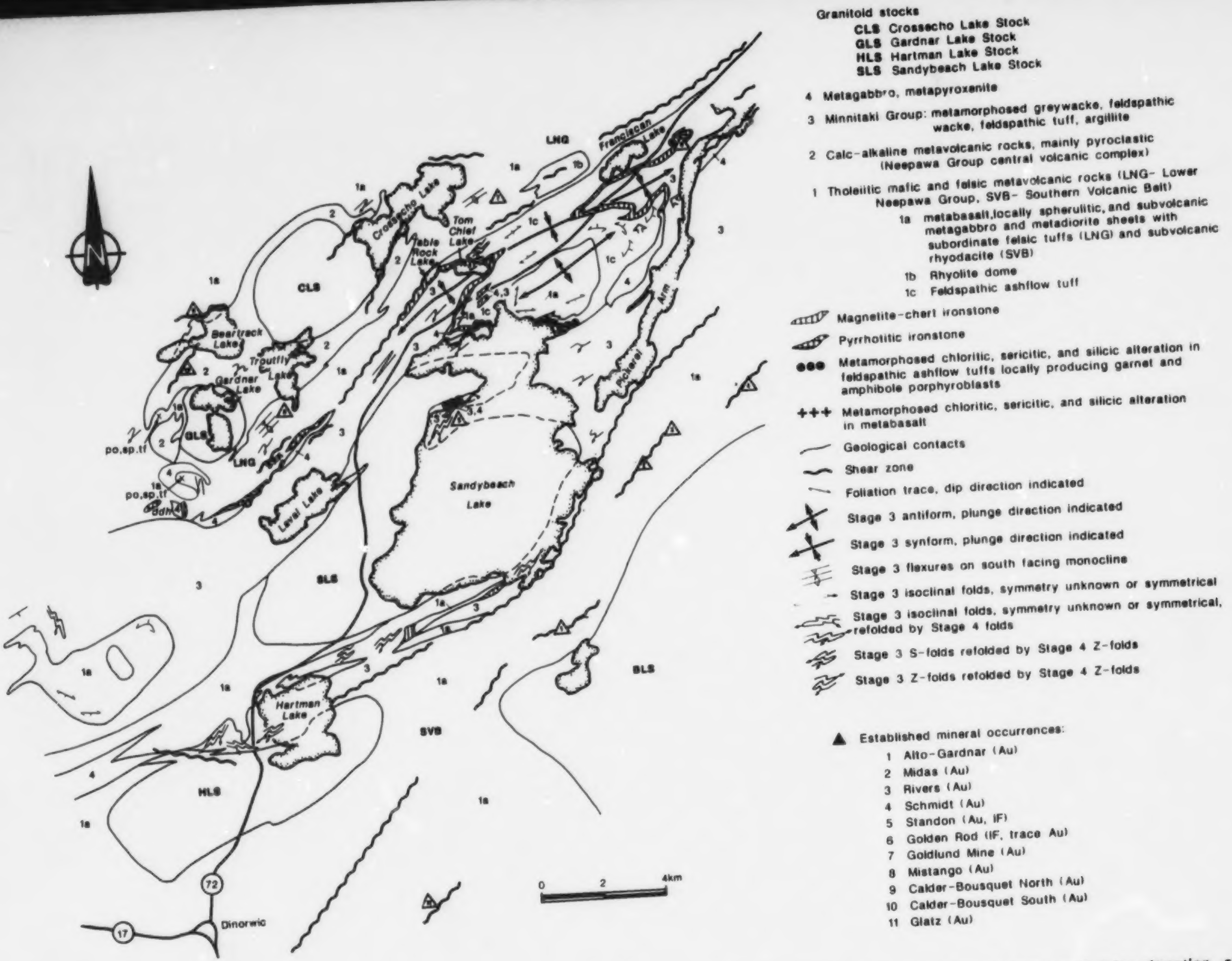
Granitoid stocks
CLS Crossecho Lake Stock
GLS Gardnar Lake Stock
HLS Hartman Lake Stock
SLS Sandybeach Lake Stock
4 Metagabbro, metapyroxenite
3 Minnitaki Group: metamorphosed greywacke, feldspathic wacke, feldspathic tuff, argillite
2 Calc-alkaline metavolcanic rocks, mainly pyroclastic (Neepawa Group central volcanic complex)
1 Tholeiitic mafic and felsic metavolcanic rocks (LNG- Lower Neepawa Group, SVB- Southern Volcanic Belt)
1a metabasalt,locally spherulitic, and subvolcanic metagabbro and metadiorite sheets with subordinate felsic tuffs (LNG) and subvolcanic rhyodacite (SVB)
1b Rhyolite dome
1c Feldspathic ashflow tuff
Magnetite-chert ironstone
Pyrrhotitic ironstone
●●● Metamorphosed chloritic, sericitic, and silicic alteration in feldspathic ashflow tuffs locally producing garnet and amphibole porphyroblasts
+++ Metamorphosed chloritic, sericitic, and silicic alteration in metabasalt
Geological contacts
Shear zone
Foliation trace, dip direction indicated
Stage 3 antiform, plunge direction indicated
Stage 3 synform, plunge direction indicated
Stage 3 flexures on south facing monocline
Stage 3 isoclinal folds, symmetry unknown or symmetrical
Stage 3 isoclinal folds, symmetry unknown or symmetrical, refolded by Stage 4 folds
Stage 3 S-folds refolded by Stage 4 Z-folds
Stage 3 Z-folds refolded by Stage 4 Z-folds
▲ Established mineral occurrences:
1 Alto-Gardnar (Au)
2 Midas (Au)
3 Rivers (Au)
4 Schmidt (Au)
5 Standon (Au, IF)
6 Golden Rod (IF, trace Au)
7 Goldlund Mine (Au)
8 Mistango (Au)
9 Calder-Bousquet North (Au)
10 Calder-Bousquet South (Au)
11 Glatz (Au)
N
LNG
Franciscan Lake
Crossecho Lake
Table Rock Lake
Tom Chief Lake
Beartrack Lake
Troutfly Lake
Gardnar Lake
Laval Lake
Sandybeach Lake
Pickerel Arm
Hartman Lake
CLS
GLS
SLS
HLS
SVB
po,sp,tf
po,sp,tf
Dinorwic
72
17
0
2
4km

Figure 22.2. *Simplified geological map of the Sandybeach Lake area indicating the major rock units, the ironstone and zones of most intense underlying alteration, and style of structures.*

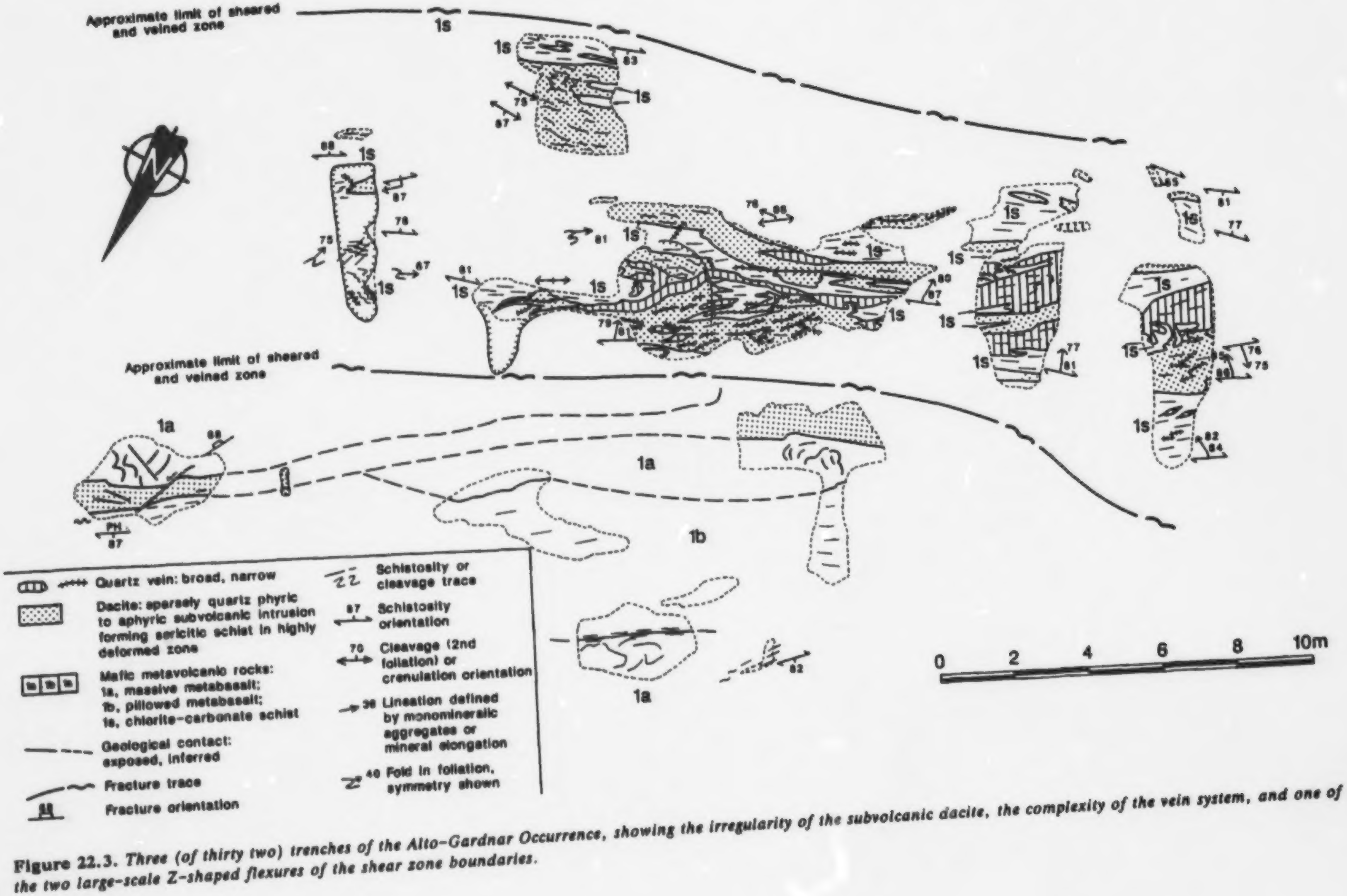
Approximate limit of sheared and veined zone
1s
1a
1b
Approximate limit of sheared and veined zone
0 2 4 6 8 10m
Quartz vein: broad, narrow
Dacite: sparsely quartz phyric to aphyric subvolcanic intrusion forming sericitic schist in highly deformed zone
Mafic metavolcanic rocks: 1a, massive metabasalt; 1b, pillowed metabasalt; 1s, chlorite-carbonate schist
Geological contact: exposed, inferred
Fracture trace
Fracture orientation
Schistosity or cleavage trace
Schistosity orientation
Cleavage (2nd foliation) or crenulation orientation
Lineation defined by monomineralic aggregates or mineral elongation
Fold in foliation, symmetry shown

Figure 22.3. *Three (of thirty two) trenches of the Alto-Gardnar Occurrence, showing the irregularity of the subvolcanic dacite, the complexity of the vein system, and one of the two large-scale Z-shaped flexures of the shear zone boundaries.*

senses on narrow Riedel shears, sigmoidally folded *en echelon* vein sets, and steep to moderately southwest– or southeast–plunging lineations on steep phyllonitic foliations. The shear zone and its structures are overprinted by local Z–folding, and localized shearing and dextral faulting, both especially evident around the southern end of Sandybeach Lake where the shear zones and regional grain flex. Northeasterly striking shear zones with the same structural fabric geometries continue southwest into northeasterly striking zones of shear and ankerite alteration passing through Dinorwic Lake.

ALTO-GARDNAR OCCURRENCE

The Alto–Gardnar Occurrence (Figure 22.2) consists of a quartz–minor ankerite vein system entirely enclosed in a 10 m wide shear zone overprinting metabasalt and an irregular network of small, subvolcanic dacite or trondhjemite intrusions. The mafic metavolcanic rocks are transformed into chlorite–ankerite schists, some of which were periodically flooded with Fe–carbonate and ankerite–quartz stringers during the duration of the shearing. In several trenches, these schists are locally bleached and rusty, containing fine disseminations of pyrite. The subvolcanic dacite, in various stages of transformation into sericite schist, is rarely pyritized. The larger veins of the system are composed dominantly of quartz accompanied by minor ankerite. Pyrite is the main sulphide vein mineral, in places accompanied by chalcopyrite or galena. Berger *et al.* (1987b) reported an assay of 3460 ppb Au and 301 ppm Cu from one of the largest quartz veins. A grab sample of the rusty schist yielded 350 ppb Au (Geoscience Laboratories, Ontario Geological Survey, Toronto).

The system of quartz and carbonate veins and deformed subvolcanic dacite bodies in the Alto–Gardnar shear zone is exceptionally complex (Figure 22.3), and the indicators of its initial sense of displacement may have been obscured by the strong imprint of later deformation. Steeply southeasterly to northwesterly dipping phyllonitic foliations and strong lineations plunging either steeply southwest or east–southeast to southeast, depending on the dip direction of the main foliation, are characteristic of this shear zone. The main foliation is folded by small–scale, gently to steeply northeast–plunging S–folds and moderately southwest–plunging Z–folds. Two large–scale Z–folds, accompanied by several minor, shear parallel faults, affect the shear zone and vein system as a whole (Figure 22.3). The late quartz veins strike counterclockwise to, and dip southeast of the main, phyllonitic foliations of the shear zone, and are sigmoidally folded about gently northeasterly plunging hinges with an S–asymmetry on both the horizontal plane and on the vertical plane looking northeast. Consideration of all data favours the interpretation that, after an uncertain early history, there was a major period of predominantly southeast–side–up, subordinately sinistral shear followed by a late period of deformation which produced the Z–folds and late faults.

MIDAS OCCURRENCE

The Midas Occurrence (Figure 22.2), where two shafts were sunk, is composed of a chlorite–ankerite schist zone up to 5 m wide cut by metre scale quartz veins (site of the western shaft), bordered to the east by profusely quartz veined, variably foliated, carbonatized metabasalt (site of the eastern shaft). Pyrite is the main sulphide mineral in the quartz veins, accompanied by chalcopyrite, malachite, and ankerite. A grab sample of vein from the western shaft assayed 2350 ppb Au and 208 ppm Cu, and a similar vein sample from the eastern shaft assayed 590 ppb Au and 320 ppm Cu (Geoscience Laboratories, Ontario Geological Survey, Toronto). Berger *et al.* (1987a) reported an assay of 1030 ppb Au and 345 ppm Cu for a vein sample from the eastern shaft. Pyrite is disseminated locally in the carbonatized wall rock, especially in the western, schistose zone. Tourmaline (schorl) occurs in the altered wall rock and replaces mafic xenoliths in the veins.

Two quartz veins exposed on the walls of the western shaft dip southeast of the phyllonitic foliations, the later one shallowly, and are sigmoidally folded with S–asymmetry on the plane of northeast vertical wall of the shaft. The phyllonitic fabrics of the schists dip moderately to steeply southeast with a southeast–plunging, down–dip lineation. Both structural relationships support a predominantly southeast–side–up displacement sense.

RIVERS OCCURRENCE

The Rivers Occurrence (Figure 22.2) is hosted by massive and pillowed metabasalt cut by subvolcanic dacite or trondhjemite bodies. These rocks are moderately to mildly foliated, with a few localized zones of intense foliation and faint steeply southwest–plunging lineation. Numerous, planar to mildly curviplanar quartz veins infiltrated the northeasterly striking, steep foliation and north–northeasterly to northerly striking fractures. Inconsistent crosscutting relationships suggest that both foliation and fracture planes were opened and filled nearly simultaneously. The array of structural observations suggests that the Rivers vein system may be situated in a structural panel or horse adjacent to major shear zones similar to the Midas and Alto–Gardnar shears, and that the quartz veins and mineralization infiltrated already existing foliations and fractures upward and laterally from these shears.

These veins consist of quartz, rarely accompanied by ankerite, and contain pyrite, sphalerite, galena, and chalcopyrite as sulphide minerals. A grab sample of vein assayed 5510 ppb Au and 0.32 ounce per ton Ag (Geoscience Laboratories, Ontario Geological Survey, Toronto). The metabasalts are heavily calcified, and locally pyritized and silica–

flooded next to veins, especially at contacts with felsic intrusive rocks. Ankeritization of wall rock is uncommon.

SCHMIDT OCCURRENCE

The Schmidt Occurrence (Figure 22.2) is hosted by metabasalt and felsite displaying intense iron carbonatization, and abundant veins in phyllonitic schists with subvertical lineations and local steeply plunging folds of the strong foliation. Ankeritized wall rock and numerous quartz and ankerite veins contain abundant sphalerite, galena, and pyrite. Grab samples of sulphide-bearing quartz vein yielded 0.82 and 0.39 ounce per ton Au, and carbonatized felsite yielded 3.57 ounces per ton Au (Geoscience Laboratories, Ontario Geological Survey, Toronto). The metabasalt is brecciated and calcified beside the ankeritized zone.

GLATZ OCCURRENCE

Mafic metavolcanic rocks at the Glatz Occurrence (Figure 22.2) were fractured and veined with quartz before the intrusion of fine feldspar–phyric granitoid rock. Both rocks were subsequently ankeritized and pyritized. On the northwestern side of the occurrence, a mafic dike intruded rebrecciated, ankeritized granitoid rock. Assays of 3090 ppb Au and 4330 ppb Au (Geoscience Laboratories, Ontario Geological Survey, Toronto) were obtained from grab samples of pyritized metabasalt and granitoid rock, respectively. A relatively minor, northeasterly striking shear zone with southwesterly plunging lineations is located southeast of the occurrence.

SUMMARY

Gold mineralization in all of the occurrences described above is related to northeasterly striking shear zones. At the Alto–Gardnar, Midas, and Schmidt occurrences, quartz veining and alteration was focused syntectonically along individual shear zones. Vein mineralization at the Rivers Occurrence occurred during activity on a neighbouring shear zone, which may have been the main hydrothermal conduit. At the Glatz Occurrence, quartz veining, followed by granitoid emplacement, preceded the carbonatization and pyritization associated with gold, and the shear zone is located to one side. The brecciation prominent at both Schmidt and Glatz occurrences may have enhanced the focusing of mineralization.

CHARACTER AND SETTING OF THE BASAL IRONSTONE

GENERAL GEOLOGICAL SETTING

The ironstone occupies the boundary between the metavolcanic Neepawa Group and the mainly metasedimentary Minnitaki Group (Figure 22.2). The Minnitaki Group in this area is composed mainly of metagreywacke, with numerous interbeds of quartzofeldspathic volcanogenic sandstone, crystal–lithic tuff, and feldspathic ashflow deposits, and less common flows and dikes of metaandesite to metabasalt. The Neepawa Group in this area is composed of a lower division consisting of tholeiitic metabasalt with subordinate metarhyodacite and metarhyolite, and an upper division consisting of metamorphosed calcalkalic dacite, andesite, and basalt with a large proportion of pyroclastic rocks in a central volcanic complex concentrated between Crossecho and Beartrack lakes (Figure 22.2). Where juxtaposed, the Minnitaki Group overlies rocks of the lower division of the Neepawa Group, an extensive dacitic ashflow in the northern part of the area, and mafic with subordinate felsic metavolcanic rocks in the south. The relative ages of the upper Neepawa central volcanic complex and the Minnitaki Group are uncertain. All units have been subjected to multi–phase deformation and greenschist to amphibolite facies metamorphism.

MAGNETITE–CHERT IRONSTONE

The ironstone consists of recrystallized magnetite–chert ironstone throughout most of the area. Centimetre–scale banding and millimetre–scale lamination are marked by variable amounts of fine–grained, wispy magnetite and amphibole. A distinctive intraformational breccia interbed, composed of flaggy chert fragments in a magnetite–rich amphibolitic matrix, can be traced throughout the northern half of the area. The northern exposure of ironstone at the Standon Occurrence on Sandybeach Lake (Figure 22.2) is relatively magnetite rich, and shows only millimetre–scale laminations.

The upper contact of the magnetite–chert ironstone with the metasedimentary rocks is clearly transitional. In the southern half of the region, it consists of magnetitic chert bands interbedded with metagreywacke, and, in places, amphibolite or amphibolitic wacke. Massively bedded, rusty weathering, feldspathic wacke, and rarely, banded argillite, both with local chert bands, overlie the ironstone north of Sandybeach Lake and west of Laval Lake. One or more sill–like bodies of fine–grained metagabbro with local metapyroxenite were emplaced along the Minnitaki Group–lower Neepawa Group contact zone mainly above the ironstone (Figure 22.2). Diamond–drill records (Assessment Files, Resident Geologist's Office, Ministry of Northern Development and Mines, Sioux Lookout) and surface exposures suggest that the metagabbro may have intruded the ironstone and the underlying metavolcanic rocks west of Pickerel Arm.

The lower contact of the magnetite–chert ironstone with the lower Neepawa Group metavolcanic rocks is abrupt, although the underlying dacitic ashflow locally shows alteration near the contact which may be linked to the presence of the ironstone. Near the Golden Rod shaft (Figure 22.2), the dacitic ashflow below the ironstone exhibits patches of intense sericitization surrounded by nebulous patches enriched in amphibole, chlorite, and porphyroblastic magnetite. At the northern end of Sandybeach Lake, this ashflow locally shows similar patchy sericitization, in both sharp and diffuse contact with lenses, patches, and even bands, of garnetiferous, variably pyrrhotitic amphibolite (Photo 22.1).

Around the northern perimeter of Sandybeach Lake, these altered ashflow tuffs were locally strongly foliated premetamorphically (Stage 1 deformation outlined below), resulting in tectonically banded feldspathic gneiss consisting of variably garnetiferous quartzofeldspathic bands with local layers enriched in coarse amphibole porphyroblasts, in both gradational and sharp contact with bands of garnet–rich amphibolite. The porphyroblasts of garnet and amphibole overprint the Stage 1 foliation, and were likely the products of peak metamorphic recrystallization (Stage 2) of an pre–existing chloritic, sericitic, and/or carbonaceous alteration, which must have post–dated Stage 1 because altered patches showed no specific localization along the Stage 1 fabrics and high strain zones. Although metamorphically recrystallized, the composition and uneven distribution of the mafic alteration are reminiscent of the broadly distributed regional alteration zones reported underneath or surrounding alteration pipes associated with base–metal massive sulphide deposits (Franklin *et al.* 1981).

PYRRHOTITIC IRONSTONE

The banded magnetite–chert ironstone can be followed from the north–central part of the area for at least 2 km southwest of Tablerock Lake, into the southeastern side of a prominent north–northeasterly striking shear zone which follows the contact with metavolcanic rocks. Four kilometres to the southwest, another type of ironstone appears within and along the northwestern side of the shear zone. This ironstone consists of thickly bedded to massive felsic volcaniclastic rock in which a dark, pyrrhotite–rich matrix surrounds felsic spherulites and cobble–sized rhyolite breccia fragments. Smaller siliceous breccia fragments show up indistinctly on fresh surfaces of the matrix, which may contain up to 40 percent pyrrhotite. Porphyroblastic garnet is developed locally. Diamond drilling of airborne geophysical anomalies along the Minnitaki Group–Neepawa Group contact encountered pyrrhotite facies ironstone southwest of Gardnar Lake (Berger *et al.* 1988a). Bedded spherulitic rocks exposed to the west of the Gardnar Lake Stock also contain minor pyrrhotite. Structural attitudes suggest that they could all be part of the same horizon.

Along the northwestern side of the pyrrhotitic ironstone, pillowed and massive metabasalt show inhomogeneously developed patches of grey–white sericitic alteration contrasting with dark green chlorite–actinolite rich seams and patches. This is also reminiscent of the alteration broadly distributed around base–metal deposits described by Franklin *et al.* (1981). Sulphide–bearing interpillow material in one of the outcrops of pillowed metabasalt near the pyrrhotitic ironstone horizon yielded 1180 ppm Cu, 6750 ppm Zn, and 50 ppb Au (Berger *et al.* 1988a), and a grab sample of pyrrhotitic ironstone gave an assay of 149 ppm Cu, 1680 ppm Pb, and 410 ppm Zn (Geoscience Laboratories, Ontario Geological Survey, Toronto). It is tentatively proposed that the alteration of the metabasalt and the formation and/or sulphide mineralization of this

Photo 22.1. *Metamorphosed (garnetized) patchy chloritic and/or carbonaceous, pyrrhotitic alteration of dacitic ashflow north of Sandybeach Lake.*

ironstone are products of hydrothermal activity potentially related to base–metal mineralization.

Attention should be drawn here to the overall configuration of the ironstones, the alteration, and the central calcalkalic volcanic complex, which field relations permit to be equivalent in age to deposition of sediments and volcanics in the Minnitaki basin. If this timing is correct, the alteration style described above on the flanks of a domed or collapsed volcanic centre should indicate potential for more substantial massive sulphide mineralization (Franklin *et al.* 1981; Knuckey *et al.* 1982).

GOLD POTENTIAL OF THE IRONSTONE

Although no anomalous gold values have yet been obtained from the pyrrhotitic ironstone, anomalous gold values have been reported in samples of the magnetite–chert ironstone which contain minor pyrite and arsenopyrite. Pyrite and arsenopyrite replace fine–grained magnetite adjacent to quartz veinlets in the ironstone at the Standon Occurrence from which Berger *et al.* (1987a) collected a grab sample yielding 1620 ppb Au. Johnstone (1969) obtained an assay of 0.01 ounce per ton Au from a grab sample taken from the dump of the Golden Rod shaft, where minor porphyroblastic pyrite partially replaces fine–grained magnetite.

In general, the pyrite appears as nodular concentrations, and as fracture, parting, and foliation plane fillings, especially where the ironstone is tightly folded. Underlying rocks may be sporadically pyritized in a similar fashion, for example at Tom Chief Lake. South of Franciscan Lake, sulphide occurs along fractures in the metagreywacke above the ironstone. In a late fault zone at Tablerock Lake, ironstone is almost completely pyritized, and only tiny, relict, magnetite–chert ironstone chips are still recognizable.

From its modes of occurrence, the pyrite in the magnetite chert ironstone appears to have been introduced during the later stages of deformation. Because the same late stage deformation controlled gold mineralization in the metavolcanic terrane (Chorlton 1987), the presence of pyrite might be used as a favourable indicator in exploring the ironstone for gold.

TECTONIC DEVELOPMENT

DEFORMATION STAGES

The results of this and previous work during this project suggest that the tectonic development post–dating volcanism and sedimentation occurred in four major stages, each responsible for a variety of structural effects. These stages and their effects are summarized as follows:

Stage 1 – Premetamorphic Deformation

1—This stage resulted in the inhomogeneous development of gently to moderately dipping foliations, and localized shear zones, the latter being most prominent between Gardnar and Troutfly Lakes, and around the northwestern end of Sandybeach Lake. It is not known whether regional lineations were formed during the first deformation. Stage 1 foliations show only slight inclination to bedding and lithological contacts for the most part, and are axial planar to several fold hinges defined by the Minnitaki–Neepawa Group contact and the ironstone at northeasterly plunging northeastern end of a later doubly plunging antiform in the Stage 1 foliation (Figure 22.2, arrows).

Stage 2 – Deformation Related to Emplacement of Plutons

2—The emplacement of the Crossecho Lake, Gardnar Lake, Hartman Lake, and Sandybeach Lake granitoid stocks produced localized structural effects on the country rocks. Narrow, steep contact dynamothermal aureoles were formed around the smaller Crossecho and Gardnar Lake stocks, and wide contact zones and thermal aureoles about the larger Sandybeach Lake and Hartman Lake stocks. Broad–scale differential rotation probably occurred outside the dynamothermal aureoles of all of the stocks. Mineral lineation may have formed at this stage, which coincided with the attainment of metamorphic peak temperatures and recrystallization. The predominant regional southwesterly trends of the lineations in the country rock are similar to the lineations defined by hornblende in the Sandybeach Lake Stock. Extension lineations could have been either formed, or modified from Stage 1 lineations.

Stage 3 – Southeast–Northwest Regional Shortening and Concomitant Oblique–Slip

3a—During the third stage of deformation, earlier primary markers and tectonic fabrics were deformed into large amplitude folds and isoclinal parasitic folds. The doubly plunging antiform–synform in the early fabrics, nearly coincident with the dome and saddle structure defined by the ironstone and the metasedimentary–metavolcanic contact in the northern half of the area (Figure 22.2), belongs to this deformational event. The large–scale folds are fairly open due to the buttressing effect of the Sandybeach Lake Stock; similarly, rolls in earlier foliation are relatively open in the lee of the Gardnar Lake Stock. Elsewhere in the area, Stage 3 folds are essentially isoclinal, and commonly display a large variation in plunge. Overprinting or modification of both extension and mineral lineations may have occurred during this stage, during which peak metamorphic conditions persisted.

3b—The folding coincided with the development of steep, northeasterly striking shear zones which are primarily sinistral in horizontal component. An equal to predominant southeast–side–up vertical shear characterizes the main stages of shear on the shear zones east of Sandybeach Lake. West of Sandybeach Lake, the main shear zones are broadly spaced, and local rotated porphyroclasts and *en echelon* arrays of sigmoidal extension gashes suggest a greater lateral component of shear.

3c—Fracturing and quartz vein emplacement, accompanied locally by carbonatization and albitization related to gold mineralization, occurred during ongoing development of shear zones, rotation and shear strain of the terrane between shear zones, and tightening of the Stage 3 folds.

Stage 4 – Further Regional Shortening and Oblique–Slip

4a—During Stage 4, Stage 3 foliations, shear zones, earlier folds and lithological contacts were overprinted by small– and medium–scale folds about northeasterly to north–northeasterly striking axial planes and crenulations. Because the regional grain prior to Stage 4 was predominantly clockwise to these planes, they are predominantly Z–folds. Where the prior fabrics were acutely counterclockwise or perpendicular, the folds show S– or M–asymmetry, respectively.

4b—Late, northwesterly to westerly striking shear zones of short strike length overprinted earlier shear zones, folds, and fabrics. Their displacement sense was dextral with an unknown vertical component. Minor conjugate, northwesterly and northerly to north–northeasterly striking shear fractures are also common.

INFLUENCE ON THE MAP PATTERN

The superposition of Stage 3 folds and shear zones, folded or refolded by subordinate Stage 4 folds, on the moderately to gently dipping envelope of the stratigraphy (and early foliations) are the main controls on the map pattern. In the northern part of the area, the traces of the main metasedimentary–metavolcanic contact, the ironstone, and the metagabbro intrusions define a doubly plunging, upright anticline–syncline pair which roughly coincides with a Stage 3 antiform–synform in the early, premetamorphic foliation (Figure 22.2). Parasitic to this antiform–synform structure are local isoclinal folds, most prominent at Tom Chief Lake and the Golden Rod Shaft, and responsible for outliers of metasedimentary rock in shallowly plunging, synformal keels south of Tom Chief Lake.

South and southwest of Sandybeach Lake, irregular metasedimentary wedges and bands appear to interdigitate with mafic metavolcanic rocks on the map. Based on the assumption that they were all south–facing, Satterly (1941) defined these bands, as well as the Neepawa Group, as four individual stratigraphic formations: Brownridge volcanics, Thunder Lake sediments, Thunder River volcanics, and Zealand sediments. However, the metasedimentary rocks are identical to those of the Minnitaki Group, and the metavolcanic rocks resemble amphibolitized mafic flows of the lower Neepawa Group. Numerous Stage 3 isoclinal S–, M– or W–, and Z–folds, refolded more openly by Z–folds, were observed within all of the metasedimentary tracts (Figure 22.2 and Photo 22.2). Reversals in facing are thus clearly indicated. The interfingering on the map plane is therefore interpreted as the result of the Stage 3 isoclinal folding of a single, originally moderately or gently dipping, metasedimentary–metavolcanic contact. Variations in plunge probably produced the beginning of a dome and basin pattern. Stage 4 Z–folds and shear zones accentuated

Photo 22.2. *Open Stage 4 Z–folding of Stage 3 isoclinal folding of feldspathic beds in metagreywacke and a strong earlier foliation in a metasedimentary inlier west of Hartman Lake.*

the pronounced variations in plunge of the earlier folds and the irregularities of the contact pattern.

SIGNIFICANCE TO MINERAL EXPLORATION

Four major points may be useful to those engaged in mineral exploration:

1. This study provides further support for the base–metal potential of the lower Neepawa Group surrounding the central volcanic complex northwest of Sandybeach Lake, particularly in the vicinity of spherulitic tuff horizons, the pyrrhotitic ironstone, and the contact zone between the Neepawa Group and the Minnitaki Group. The pyrrhotitic ironstone itself locally shows indications of base–metal mineralization, and altered rocks underlying both the pyrrhotitic and magnetite–chert ironstones may also be worthy of investigation for base metals.
2. The doubly plunging, antiform–synform structures, the local tight parasitic folds, and potential outliers of younger rocks in saddles or crests may be factors to consider in exploration, not only in searching for structural settings favourable for gold, but for investigating specific stratigraphic horizons, positioning diamond–drill holes, and interpreting core logs. Attention should be paid to the pattern defined by the nearest contacts with the metasedimentary tracts when exploring metavolcanic rocks. The geometry of mesoscale folds visible in those metasedimentary tracts, although admittedly complex, might also prove useful.
3. Gold mineralization is mainly controlled by Stage 3 shear zones, folds, and fracture zones. Outside of the terrane intruded by major granitoid stocks, most of the gold occurrences are found along shear zones. In the northeast–striking shear zones east of the Sandybeach Lake Stock, gold occurs in major systems of quartz veining, iron carbonatization, and sulphide mineralization. To the northwest of the stocks, auriferous mineralization is also clearly focused along steep shear zones at Beartrack Lake (Chorlton 1987). In the area intruded by the granitoid stocks west of Sandybeach Lake, the most important gold occurrences to date (Camreco–Goldlund Mine) accompany transverse vein sets and stockworks hosted mainly by subvolcanic intrusive sheets fractured during Stage 3 folding, rotation, and unfocused shear, rather than being focused along discrete shear zones themselves (Chorlton 1987). Throughgoing shear zone development may have been inhibited by the presence of the large stocks. However, a carbonatized shear zone, quartz vein style of potentially auriferous mineralization resumes to the northeast around Pickerel Arm.
4. The ironstone may host gold mineralization, particularly where pyritized in and around Stage 3 isoclinal fold hinges and shear zones.

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23. Project Number 88–23. A Stratigraphic Reconnaissance of the Eastern Wabigoon Subprovince

C.E. Blackburn[1] **and G.W. Johns**[2]

[1]Resident Geologist, Ministry of Northern Development and Mines, Kenora.

[2]Geologist, Precambrian Geology Section, Ontario Geological Survey, Toronto.

PURPOSE

In order to gather data for the maps and reports of the Geology of Ontario compilation and plan further studies, a five day reconnaissance survey of the eastern Wabigoon Subprovince was made in early July 1988 (Figure 23.1). The internal parts of the subprovince were briefly examined to ascertain the major stratigraphic and structural relationships. This examination will allow the authors to compare and contrast the western and eastern Wabigoon Subprovince. The area north of Highway 11 between Beardmore and Jellicoe was visited. The area of interest adjoins the southern boundary of the Wabigoon Subprovince with the Quetico Subprovince, and is being studied by Williams (1986, this volume).

REGIONAL TERRANES

For the purpose of discussion it is convenient to informally divide the area into terranes that constitute individual geologic entities with distinct rock types, structures, and possibly ages. Three regional subdivisions can be made on the basis of structural and lithologic characteristics (Figure 23.2). It has been recognized that the east–trending Geraldton–Beardmore terrane is distinctly different from the two terranes to the north, and that the Paint Lake Fault (Figure 23.3) forms the north boundary of this ter-

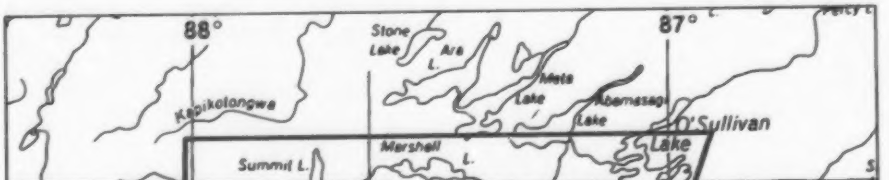
88°
87°
Stone Lake
Arc L.
Mate Lake
Abamasagi Lake
O'Sullivan Lake
Kapikotongwa
Marshall L.
Summit L.
Toronto L.
Esnagami Lake
Gzowski
Kowkash
Rupert
Esnagami
Alpha
Auden
Tashota
Ombabika Bay
Kowkash
Nakina
Oboshkegan
Suni
Danford
Exton
Nakina
Fleming L.
Onaman Lake
Murchison Island
Fauteux
50°
Humboldt Bay
Burrows Lake
Fullerton Lake
Treptow Lake
Bichle
Barbara
Meader
Pifher
Elmhirst
Rickaby
Lapierre
Hipel
Kirby
Fulford
McQuesten
Houck
Oakes
GERALDTON
N
Dorothea
Sandra
Irwin
Walters
Leduc
Legault
Coltor
Lindsley
Errington
Jellicoe
0
10
20
km
Summers
McComber
Beardmore
Vincent
Eva
Vivian
Parent
Salsberg

Figure 23.1. *Location map for the eastern Wabigoon Subprovince.*

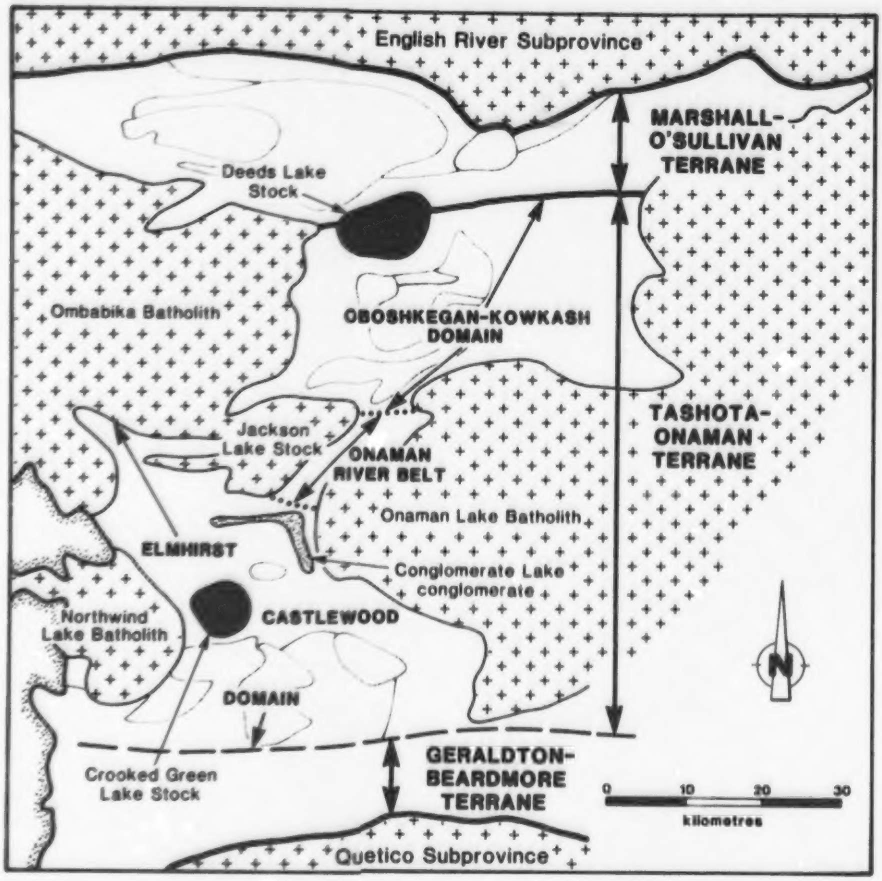
English River Subprovince
MARSHALL-O'SULLIVAN TERRANE
Deeds Lake Stock
Ombabika Batholith
OBOSHKEGAN-KOWKASH DOMAIN
TASHOTA-ONAMAN TERRANE
Jackson Lake Stock
ONAMAN RIVER BELT
Onaman Lake Batholith
ELMHIRST
Conglomerate Lake conglomerate
Northwind Lake Batholith
CASTLEWOOD
DOMAIN
N
GERALDTON-BEARDMORE TERRANE
Crooked Green Lake Stock
0
10
20
30
kilometres
Quetico Subprovince

Figure 23.2. *Subdivision of the eastern Wabigoon Subprovince into terranes between Lake Nipigon and Geraldton. See Figure 23.3 for a complete legend.*

rane (Devaney and Williams, in press). That part of the Wabigoon Subprovince to the north of the Paint Lake Fault has been here subdivided into the Tashota–Onaman terrane; and to the north of this, the Marshall–O'Sullivan terrane, which is marginal to the English River Subprovince. Most of the discussion herein is concerned with the Tashota–Onaman terrane.

GERALDTON-BEARDMORE TERRANE

The Geraldton–Beardmore terrane lies south of the Paint Lake Fault and north of the Quetico Subprovince and comprises an east–trending sequence of three fault blocks consisting of mafic volcanic units and clastic sediment units intercalated with ironstones. This terrane is commonly considered to be the boundary zone between the Wabigoon and Quetico subprovinces. Currently, these units are interpreted to be a northward–thrust sequence, with a component of dextral strike–slip movement, ascribed to northwest–southeast transpression (Williams 1986).

TASHOTA-ONAMAN TERRANE

The Tashota–Onaman terrane is similar to the western Wabigoon Subprovince in that it is predominantly a volcanic–plutonic terrane in which large crescentic areas of supracrustal rocks lie between ovoid granitic batholiths. Two such areas, the Elmhirst–Castlewood domain in the south and the Oboshkegan–Kowkash domain in the north (Figure 23.2) make up most of the terrane. They are joined by a narrow belt of volcanic rocks called the Onaman River Belt (Figure 23.2). Each domain is characterized by a major felsic volcanic centre, surrounded by large areas of more mafic volcanic rocks, intruded by granitic to gabbroic stocks (Figure 23.3). Although the stratigraphic and structural relationship between the three parts of the terrane have not been interpreted at this time, a U–Pb age of 2764 +6/–5 Ma for a felsic tuff in the Onaman River Belt (Osterberg *et al.* 1987) indicates that these rocks may predate some of the rocks in the surrounding domains.

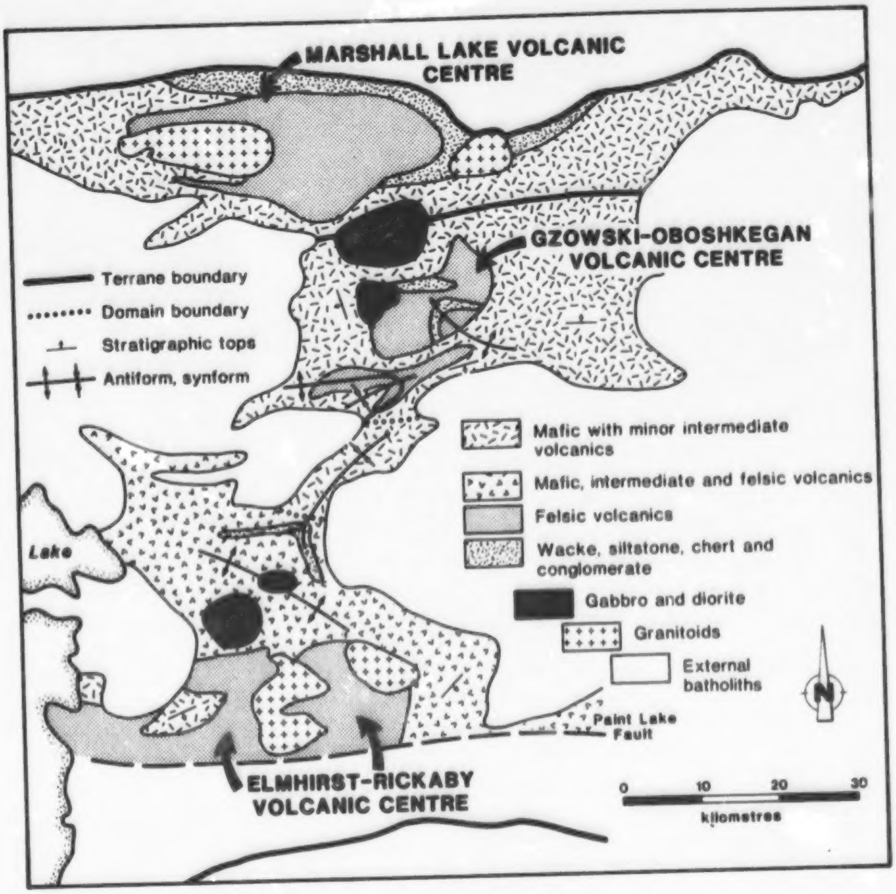
MARSHALL LAKE VOLCANIC CENTRE
GZOWSKI-OBOSHKEGAN VOLCANIC CENTRE
Terrane boundary
Domain boundary
Stratigraphic tops
Antiform, synform
Mafic with minor intermediate volcanics
Mafic, intermediate and felsic volcanics
Felsic volcanics
Wacke, siltstone, chert and conglomerate
Gabbro and diorite
Granitoids
External batholiths
N
Lake
Paint Lake Fault
ELMHIRST-RICKABY VOLCANIC CENTRE
0
10
20
30
kilometres

Figure 23.3. *Generalized geology of the eastern Wabigoon Subprovince between Lake Nipigon and Geraldton.*

MARSHALL-O'SULLIVAN TERRANE

The west-trending supracrustal sequence centred on Marshall Lake has been here designated the Marshall-O'Sullivan terrane (Figure 23.2). The northern boundary of this terrane with the English River Subprovince is defined by a sequence of predominantly clastic sedimentary rocks and intercalated ironstones that define an east-trending belt north and east of the Marshall Lake volcanic centre (Figure 23.3) (Amukun 1985). Similar sedimentary sequences occur at Melchett Lake within the English River Subprovince to the north; and may have originally formed part of the Marshall-O'Sullivan terrane.

TASHOTA-ONAMAN TERRANE

The reconnaissance work was confined to the southern two thirds of this terrane, with access being provided by the Kinghorn Road and its subsidiary roads, and Highway 801. The Elmhirst-Castlewood domain and Onaman River Belt were examined across several sections. Only a small portion of the southern part of the Oboshkegan-Kowkash domain was visited, but some critical observations were made in this area which bear on the stratigraphic succession of felsic and mafic sequences.

A major consideration of this study was the stratigraphic relationship of surrounding mafic volcanics to the felsic volcanic centres in the Elmhirst-Castlewood domain and the Oboshkegan-Kowkash domain (Figure 23.2).

In the western Wabigoon Subprovince, voluminous, platformal, lower mafic flow sequences are overlain by mixed mafic flow to felsic pyroclastic sequences, which in turn, are overlain in some places by another mafic flow sequence (Trowell *et al.* 1980). These relationships have been clearly documented by a multitude of facing criteria, substantial geochemical data, and geochronological data. Inspection of previous Ontario Geological Survey reports and maps of the Tashota-Onaman terrane suggests that facing criteria are less readily available here than in the western Wabigoon Subprovince: to date it has not been demonstrated that, in the Tashota–Onaman terrane, large areas of platformal mafic volcanics underlie the felsic volcanic centres.

ELMHIRST–CASTLEWOOD DOMAIN

The southwestern portion of this domain is underlain by a mafic volcanic sequence, synvolcanic gabbro, and an extensive accumulation of felsic volcanic rocks (Elmhirst–Rickaby felsic centre; Figure 23.3) into which three granitoid bodies have been intruded (Figure 23.2 and Figure 23.3). Top determinations by Mackasey and Wallace (1978) in the felsic volcanics in Pifher and Rickaby townships indicate that the felsic rocks are locally underlain by a mixed sequence of andesitic to basaltic flows, porphyries, and pyroclastic rocks interlayered with a lesser amount of more intermediate debris flows, porphyries, and flows. The abundance of amygdules, gas cavities, pillow breccia, and hyaloclastite indicate that these units were deposited mainly in a shallow water environment. The felsic volcanic centre is mainly composed of monolithologic quartz–feldspar porphyry and feldspar porphyry pyroclastic flows and lava flows. A highly spherulitic felsic flow in Rickaby Township is indicative of supercooled magma that may have erupted subaerially. This felsic volcanic centre is cut by mafic dikes that may be feeders for overlying flows.

In Lapierre Township, east of the Elmhirst–Rickaby felsic volcanic centre, large gas cavities, amygdules, and the lack of pillows within the mafic to intermediate flows indicate that this sequence was emergent. Here this sequence faces south; its stratigraphic relationship to the felsic volcanic centre in Elmhirst and Rickaby townships however, is not clear.

The mixed sequence of rocks underlying the felsic volcanic centre is similar in its overall nature to the Upper Diverse Units found by the writers in the western Wabigoon Subprovince. We could not clearly demonstrate the presence of an extensive Lower Mafic Unit which is present in the western Wabigoon Subprovince (Trowell *et al.* 1980).

In the Elmhirst–Castlewood domain, the mixed sequence of shallow water, mafic, and intermediate volcanics was intruded by several subcircular dioritic to gabbroic stocks. The Crooked Green Lake Stock (Figure 23.2), the only one checked by the authors, has imparted a pronounced foliation to the surrounding volcanics, but is not itself foliated, suggesting that it is syntectonic. Moorhouse (1939) interpreted the presence of large xenoliths in the stock as roof pendants and suggested that these stocks represent the upper portions of a deep-seated, unexhumed granitoid batholith.

At the north edge of the domain, a unique (to the eastern Wabigoon Subprovince) assemblage of clastic sediments overlies the volcanics at Conglomerate Lake (Figure 23.2). The sedimentary accumulation consists of conglomerate with sandstone interbeds, some of which contain crossbedding. The heterolithic conglomerate contains clasts representative of underlying volcanic rocks, including quartz–feldspar porphyries, cherty ironstones, and rocks derived from the adjacent Onaman Batholith. It is clearly a post–volcanic accumulation and is possibly representative of a Timiskaming–type pull–apart basin.

Because of the paucity of facing criteria, little can be said of the fold pattern; but the emplacement of sub–rounded dioritic to gabbroic stocks suggests gentle doming rather than tight, isoclinal folding (Figure 23.3). At the eastern edge of the domain, a strong flattening foliation in pillow lavas and breccias, parallel to the contact with the Onaman Batholith, suggests compression by batholithic emplacement in addition to doming.

ONAMAN RIVER BELT

The Onaman River Belt is a narrow, tightly–folded sequence of mafic flows, felsic pyroclastics, and ironstones forming a bridge between the Elmhirst–Castlewood domain and the Oboshkegan–Kowkash domain (Figure 23.2). Numerous top determinations by Thurston (1980) and by the authors during these investigations, suggest tight isoclinal folding about several northeast–trending fold–axes (Figure 23.3). The distribution of chert–rich ironstones near the northwest and southeast edges of the belt, suggests a synclinal structure for the belt. This structure, extended to the southwest, joins the synclinal axes of the sediments on Conglomerate Lake (Figure 23.2) in a triple–syncline junction (Figure 23.3).

OBOSHKEGAN–KOWKASH DOMAIN

A review of the literature (Mackasey and Wallace 1978; Amukun 1977, 1979, 1980a, 1980b, 1985, 1987; Kresz and Zayachivsky 1988) suggests that this domain is similar in many respects to the Elmhirst–Castlewood domain; the structural style is broad open folds with a felsic volcanic centre (the Gzowski–Oboshkegan volcanic centre; Figure 23.3). Relatively mature sediments, derived from the felsic and mafic volcanic rocks, cherts, and chert breccias (Amukun 1980a) appear to overlie the volcanic rocks.

The Gzowski–Oboshkegan felsic volcanic centre (Figure 23.3) is interpreted by the authors on the basis of available mapping (Amukun 1980a), to comprise volcanic domes with flanking talus or crumble breccia that give way to primary pyroclastic flows. In the southwest portion of the domain, the felsic volcanics are monolithic with matrix–supported feldspar to quartz–feldspar porphyry clasts in thick, massive beds. As little bedding was observed, these pyroclastic flows were interpreted to have been deposited rapidly in a proximal environment.

The syenodioritic to dioritic Deeds Lake Stock (Figure 23.3) bears a similarity to the Crooked

Green Lake Stock and other dioritic stocks in the Elmhirst–Castlewood domain, whereas other more felsic stocks are similar to those intruding the Elmhirst–Rickaby felsic volcanic centre.

Top determinations made during this reconnaissance work in the southwest corner of the domain indicate that mafic volcanics on either side of a felsic pyroclastic unit face away from that unit. This indicates that an east–northeast–trending anticlinal structure is cored by the felsic rocks and the mafic volcanis overlie them (Figure 23.3). Opposing top determinations made by Amukun (1980a) in the clastic sediments in this area indicate a similar east–northeast–trending syncline in those rocks (Figure 23.3). Map patterns on map 2354 (Amukun 1977) suggest that by extension of the anticlinal axis through the felsic volcanics, that this axis has been refolded about a syncline (Figure 23.3). This series of interpretations contradicts a number of top determinations in the pillowed volcanics made by Amukun (1977); however, it should be noted that top determinations made by the present authors in the road section at two separate localities also contradict those determinations made at the same localities by Amukun (1977).

Observations outlined in the foregoing paragraph suggest that at least some of the mafic volcanics in the Oboshkegan–Kowkash domain overlie the felsic sequences.

STRATIGRAPHIC SUCCESSION, AND COMPARISON WITH THE WESTERN WABIGOON SUBPROVINCE

The shortage of unequivocal top determinations, coupled with low outcrop density, hinders the correlation of units. Also, the lack of precise geochronological data makes stratigraphic analysis tenuous. The evidence presented in the previous sections suggests that mafic volcanic sequences underlie and overlie the mafic and felsic to intermediate pyroclastic and flow sequences within the Tashota–Onaman terrane. This mixed mafic and intermediate to felsic flow and pyroclastic sequence may also be similar to Upper Diverse units, and in these respects, the terrane resembles the internal terranes of the western Wabigoon Subprovince. However, evidence for extensive basal mafic flow successions, similar to those found in the western Wabigoon Subprovince, is lacking in the Tashota–Onaman terrane.

Late, post–volcanic clastic sediments with apparent unconformities at their bases are present at both Conglomerate Lake (Amukun 1980b), and possibly at Knucklethumb Lake (Amukun 1977). Their limited extent is in sharp contrast to the western Wabigoon Subprovince, where the Manitou group and correlative sediments occur along a linear zone in excess of 100 km long (Blackburn 1982).

FELSIC PLUTONS

During this reconnaissance work, little attention was given to the batholiths that occur along the margin of the Tashota–Onaman terrane. However, a few observations and comments are in order.

Three batholiths are external to the terrane: the Onaman Lake Batholith, the Ombabika Batholith (Lamaune Batholith (McCrank *et al.* 1981)) and the North Wind Lake Batholith (Figure 23.2). The latter was not visited during this reconnaissance study.

ONAMAN LAKE BATHOLITH

Clasts similar in texture and composition to phases of this batholith were observed in the conglomerates at Conglomerate Lake, indicating that the batholith was emplaced prior to deposition of the sediments.

A porphyry that occurs along the southern edge of the Onaman River Belt, in the vicinity of the Tashota Mine (Thurston 1980) appears to be a subvolcanic phase of the batholith. A traverse across the transition from the porphyry to the biotite granodiorite or trondhjemite of the batholith revealed no sharp contact.

OMBABIKA (LAMAUNE) BATHOLITH

The Jackson Lake Stock, which is part of the Ombabika (Lamaune) Batholith, and was observed along the road north of the Onaman River, is an unmetamorphosed quartz monzonite to granodiorite. There is no indication on Thurston's (1980) or Amukun's (1977) maps of marginal porphyry phases, as there is with the Onaman Lake Batholith. Ombabika (Lamaune) Batholith is therefore probably of later age than the Onaman Lake Batholith, and late tectonic rather than post–tectonic.

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24. Project Number 87–17. Geological Studies in the Wawa, Quetico, and Wabigoon Subprovinces, with emphasis on Structure and Tectonic Development

H.R. Williams

Geologist, Precambrian Geology Section, Ontario Geological Survey, Toronto.

INTRODUCTION

This project is concerned with regional and local structural geometry of three subprovinces, their relationships and tectonic development. A final year of field work was completed in 1988 within a 15 000 km² area, bordered by Lake Superior, Lake Nipigon, Long Lake, and Highway 11 (Figure 24.1), to carry out the following studies:

1. A number of mine and property visits allowed detailed structural examination of mineralized zones.
2. The sedimentology, stratigraphy, and structure of ultramafic sediments and breccias in the Lake Jean area were studied in detail.
3. Coarse clastic felsic volcanics and associated conglomerates were studied within the Quetico Subprovince close to the boundary with the Wawa Subprovince.
4. A study was made of the field relationships and compositions of two suites of igneous intrusions within the Quetico Subprovince.
5. Major shear zones along the Wawa–Quetico Subprovince boundary were studied along the

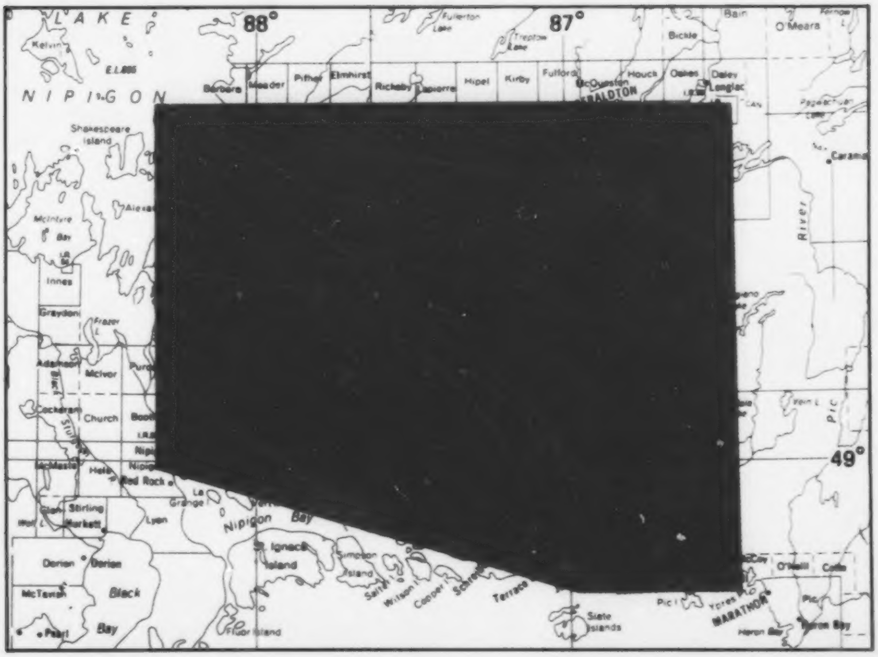
LAKE
NIPIGON
88°
87°
49°
Kelvin
Shakespeare Island
McIntyre Bay
Innes
Graydon
Adamson
McIvor
Church
Stirling
Dorion
McTavish
Black Bay
Barbara
Meader
Pifher
Elmhirst
Richardson
Lapierre
Hipel
Kirby
Fulford
Houck
Oakes
Daley
Bain
Bickle
O'Meara
Fullerton Lake
Treptow Lake
Longlac
GERALDTON
Red Rock
La Grange
Nipigon
Nipigon Bay
Lyon
Ignace Island
Simpson Island
Salter
Wilson
Cooper
Schreiber
Terrace
Slate Islands
Pic
Pic River
Caramat
O'Neill
Coldwell
Marathon
Heron Bay
Yores

Figure 24.1. *Location map for structural studies undertaken in the Wawa, Quetico, and Wabigoon Subprovinces. Scale: 1:1 584 000 or 1 inch to 25 miles.*

This project A.5.1 is part of the five year Canada–Ontario 1985 Mineral Development Agreement (COMDA), a subsidiary agreement to the Economic and Regional Development Agreement (ERDA) signed by the governments of Canada and Ontario.

Gravel River and Quetico Faults to determine kinematics and width of expression.

The newly acquired data has been incorporated into the tectonic scheme set out by Williams (1987) and Devaney and Williams (in press). A final report with accompanying geological maps at a scale of 1:250 000 will be completed in 1989.

GEOLOGY

MINE VISITS

The following four mine visits were made: the Ateba–Roxmark Property at the town of Geraldton, the Pan–Empire Joint Venture at the town of Beardmore, the Minnova Mine at Winston Lake (Schreiber), and the Geco Mine at the town of Manitouwadge.

The Roxmark Mine was visited to inspect the subsurface expression, continuity, and geometry of west–plunging asymmetric fold structures and associated veining characteristic of the Barton Bay Deformation Zone. The observed changes in fold plunge and amplitude are commonly found in high–strain zones and demonstrate that the absence of potentially ore–bearing fold structures at surface is an unreliable guide to deep subsurface structure.

At the Pan–Empire Mine within the Beardmore–Geraldton Belt, thin (<1 m) layers of ironstone within the southern mafic volcanic belt focus shearing to form complex fold geometries, including sheaths that imply considerable strain. Despite fold thickening and complementary thinning by shearing, there is a remarkable continuity of ironstone layers demonstrable by geophysical means (A. Stearman, Geologist, A.C.A. Howe International Ltd., Toronto, personal communication, 1988). Considerable deformation was partitioned into the ironstone–bearing layers, leaving adjacent mafic volcanics relatively undeformed.

At the Winston Lake Mine, the schistose contact between the hanging wall gabbro, ore zone, and altered footwall volcanics was examined and found to be highly sheared, with slip directions generally downdip of the schistosity. The sheared contact likely forms part of a zone of intense deformation, discontinuously preserved between Winston Lake and the town of Manitouwadge along the northern margin of the Wawa Subprovince.

The Geco Mine visit allowed lithological and structural complexities to be examined, especially for evidence of multiple deformation and its controls on ore orientation and location. Sulphide ore appears to be elongated along an early linear feature that is refolded by the Manitouwadge Synform. Sericitic alteration thought to be associated with ore deposition has focused later shearing, making ore/structure relationships complex.

ULTRAMAFIC AND RELATED CHLORITIC SEDIMENTS

These were studied in detail in the Lake Jean and Namewaminikan River sections (Williams 1987), partly in conjunction with P.W. Fralick of the Department of Geology, Lakehead University. On Lake Jean, feldspathic graded wackes pass upwards into pale– to medium–green chloritic arenites containing evidence of climbing ripples, scours, and cross–lamination, succeeded by massive to graded chloritic wackes bedded on a decimetre scale. These are overlain by several tens–of–metres of ungraded, often massive, poorly stratified, ultramafic to extremely chlorite–rich sediments and breccias, containing clasts of pale quartzitic sandstone. Vein–style alteration of the most chloritic rocks gives rise to a centimetre–scale lacework of quartz–carbonate veins. Within the chloritic ultramafic rocks, bedding is often tightly folded, atypical of the feldspathic wackes in the immediately surrounding rocks. Similar lithologies and stratigraphic relationships were found in the Namewaminikan River section.

The mafic and ultramafic sediments are thought to represent locally derived detritus developed from erosion of ultramafic protrusions within the Quetico sedimentary package. The magnesian composition of these rocks renders them difficult to detect other than by field methods. They do not appear on high–resolution magnetic maps.

SHEAR ZONES

Within the confines of the Quetico and Wawa Subprovinces, two shear zones, the Gravel River Fault and the Killala Lake–Big Duck Lake Shear Zone, were investigated in detail. In addition, the Quetico Fault to the west of Lake Nipigon was recognized east of Dog Lake on the "Thunder Bay to Armstrong" Road (Highway 527).

The Gravel River Fault was mapped in the Dickison Lake area, where additional evidence for sinistral kinematics, such as asymmetric folds, crenulation fabrics, and displacement of quartz veins, was found. The fault was active at least until during or after the migmatization of the metasedimentary rocks that are predominant in the area. Mylonitized, white, biotite granite and associated pegmatites attest to movement at least of late–Archean age on the fault. Lineations on the new planar fabrics within the zone of shearing are shallow plunging, both to the east and west. There is some evidence locally that grades of metamorphism in the surrounding metasediments are lower to the southeast of the fault than to the northwest. Initial oblique–reverse slip on a shallow, north–dipping precursor fault allowed it to be progressively rotated into verticality to be reactivated as a purely sinistral transcurrent structure. A preliminary estimate of the amount of displacement on the fault is of the order of 70 km, as determined from offset of ironstone markers.

The Killala Lake Shear Zone was examined at Killala Lake, where it consists of a zone of highly strained supracrustal and felsic intrusive rocks on the southeastern side of the lake (Coates 1970). This zone of high strain is traceable eastwards along the northern edge of the Wawa Subprovince into the Manitouwadge area, and westwards into the Big Duck Lake Shear Zone. The zone broadly corresponds with the most northerly outcrop of mafic rocks in the Wawa Subprovince. In addition, preliminary data suggest that repetition of the greenstone supracrustal stratigraphy along the northern margin of the Wawa Subprovince is in part due to imbrication by this nearly strata-parallel shear zone. The spatial association between mineralization and the high-strain zones occurring at and adjacent to this major tectonic boundary is in large part controlled by lithology and alteration.

As part of a regional study of faults and shear zones, an expression of the eastward continuation of the Quetico Fault in the area east of Dog Lake (Kennedy 1984) was sought. Outcrops along the "Thunder Bay to Armstrong" Road (Highway 527) indicate a zone of high strain within both metasedimentary migmatites and orthogneisses. A strong foliation, oriented roughly east–west, and a complementary subhorizontal mineral and stretching lineation occur in conjunction with unambiguous kinematic indicators, such as extensional crenulation fabrics and asymmetric augen structures, demonstrating that motion was predominantly dextral. Farther east, the Quetico Fault, although hidden by Proterozoic sediments and intrusions, joins with the Wawa–Quetico Subprovince boundary in the area now occupied by St. Ignace Island, and might be the controlling tectonic factor for the location of Proterozoic igneous complexes (*see* Sutcliffe and Smith, this volume) in that area.

QUETICO GRANITOIDS

Two suites of granitoid intrusions within the Quetico Subprovince were studied and sampled for geochemical and geochronological studies. The older suite is considered by Percival and Williams (in press) to be I-type; the younger, S-type, based on their petrological and geochemical similarity to rocks elsewhere in the Quetico Subprovince (Percival, in press; Kissin *et al.* 1986). It is anticipated that mineralization associated with these granitoids would be of a different character.

The older suite consists of hornblende–biotite–magnetite-bearing, quartzo–feldspathic rocks that occur as steeply dipping, concordant sheets within the highest-grade portions of the Quetico Subprovince. Some sheets have a narrow magnetic expression that coincides with their position and width; others occur within a complex pattern of regional magnetic linears which overemphasizes their width. Some bodies are insufficiently magnetic or extensive across strike to develop a characteristic magnetic expression and were found only by detailed mapping in the inhomogeneous metasedimentary migmatite terrane.

The younger suite of granitoids consists predominantly of biotite granite, with late aplitic and pegmatitic evolved phases. These may contain, as accessories, one or more of muscovite, tourmaline, garnet, apatite, and beryl. Occurrences of spodumene, beryl, and rare-earth-bearing minerals within these granites might be expected in discordant, late-stage, geochemically evolved members of this suite. In the northern part of the Quetico Subprovince, these granites are discordant, hydrous, high-level intrusions, becoming increasingly concordant, deformed, and migmatized as the central high-grade core of the Subprovince is approached.

VOLCANICS AND ASSOCIATED CONGLOMERATES IN THE QUETICO SUBPROVINCE

Within 3 km north of the Wawa–Quetico Subprovince boundary, just west of the "Terrace Bay to Geraldton" Road, a suite of conglomeratic rocks was discovered (Williams 1987) which lies along strike of some mapped by Coates (1970) in the Killala Lake area. North of the town of Terrace Bay, these rocks consist of several, metre-scale, generally monomictic conglomerates, mostly interbedded with arenaceous rocks. Some conglomerates, however, contain decimetre-sized clasts of uniform composition in a homogeneous, isotropic matrix that contains more biotite and feldspar than the matrix of the conglomerates that are interbedded with arenite.

In the Killala Lake area, Coates (1970) mapped highly deformed conglomerate on both sides of an antiformal structure. These rocks are identical in appearance to those farther west, but the distinction between volcanic rock and derived sediment is not possible because of the strain and metamorphic recrystallization that they have suffered.

These conglomeratic rock suites are considered to be examples of proximal-facies volcanics and derived sediments. Their presence indicates that the positioning of the stratigraphic boundary between the Wawa and Quetico Subprovinces at the northernmost mafic unit detracts from the fact that potentially mineralized lithologies occur north of this boundary.

DISCUSSION

Field work, in association with ongoing laboratory studies, has enabled the erection of a model to explain the development of the belt-like subprovincial structure of this hitherto little-known region. The interplay of lithology and structure, and their combined relationship with mineralization, can now be placed within the context of a regional-scale tectonic model of volcanic arc accretion. This model may be compared with Phanerozoic and Proterozoic analogues, within which the distribution and development of mineralization are well known.

ACKNOWLEDGMENTS

Constructive criticism, and logistical and technical assistance by M. Dolan (Ontario Geological Survey, Toronto) and B. Schnieders (Ministry of Northern Development and Mines, Thunder Bay) are appreciated.

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25. Project Number 88–13. Seagram Lake Area, District of Thunder Bay

D.U. Kresz and Borys Zayachivsky

Geologists, Precambrian Geology Section, Ontario Geological Survey, Toronto.

INTRODUCTION

Mapping of the Seagram Lake area was undertaken to complete coverage of the area east of Geraldton and investigate two major east–trending deformation zones known to host gold mineralization. The Theresa Mine, which produced 4785 ounces of gold between 1935 and 1955, is located near the western boundary of the map area. The surveyed area, bounded by Latitudes 49°37′30″N and 49°50′25″N and Longitudes 86°32′50″W and 86°15′W, covers 500 km² and includes Daley Township and Longlac Indian Reserve 77 (Figure 25.1).

Access to the map area is provided by Trans–Canada Highway 11, Highway 625, the Canadian National Railway, the Trans–Canada gas pipeline right–of–way, and by numerous gravel roads. The southern part of the map area may be reached by watercraft through McKay Lake. The Town of Longlac lies in the western part of the map area.

MINERAL EXPLORATION

Gold was first discovered at Geraldton in 1931 and the exploration activity that followed resulted in the discovery of many gold mines and occurrences.

Renewed interest in gold has prompted exploration activity in the Northern Long Lake area (Kresz and Zayachivsky 1987) and in the western part of the present map area.

Duration Mines Limited have concentrated exploration and development activity around the old Theresa Mine (Mason and White 1986) south of

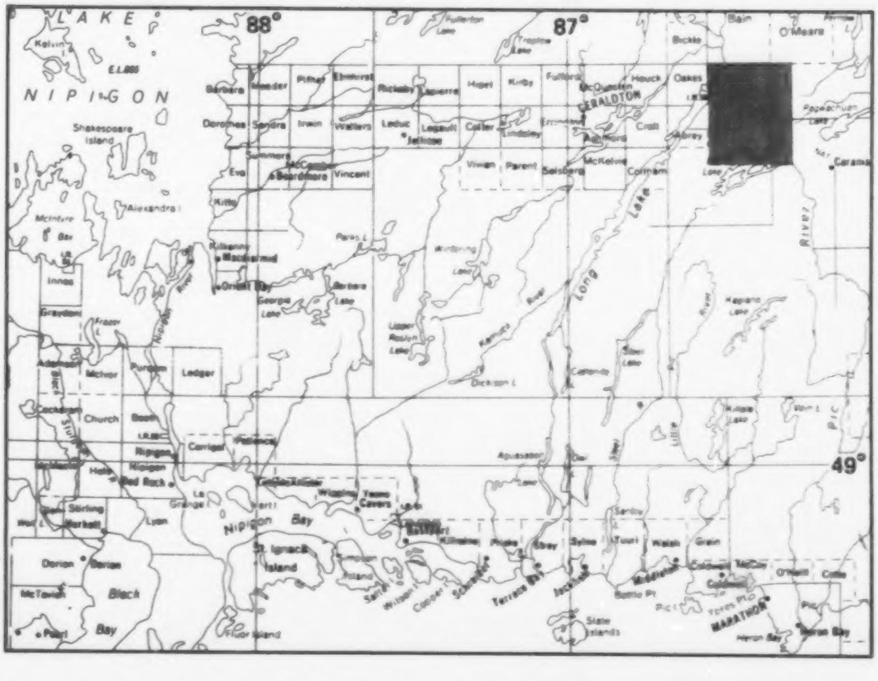

Figure 25.1. *Location map for the Seagram Lake Area. Scale: 1:1 584 000 or 1 inch to 25 miles.*

This project A.5.1 is part of the five year Canada–Ontario 1985 Mineral Development Agreement (COMDA), a subsidiary agreement to the Economic and Regional Development Agreement (ERDA) signed by the governments of Canada and Ontario.

Longlac. Surface and underground diamond drilling followed the dewatering of the main shaft in 1987.

Discovery West Corporation holds a large claim block south and west of the Duration Mines Limited property. A power stripping, trenching, and sampling program, mainly outside the present map area, was in progress in 1988.

Following the discovery of visible gold in quartz veins in Oakes Township by Bill and Rachel Brinklow (Prospectors, Manitouwadge, personal communication, 1987), Gold Crest Minerals Incorporated have acquired a claim block north of Longlac in 1988.

In 1958 and 1959, Can–Fer Mines Limited followed by Hanna Mining Company and the Algoma Steel Corporation Limited in the 1960s examined the iron formations in the eastern part of the map area.

GENERAL GEOLOGY

The area (Figure 25.2) has been previously mapped by Fairbairn (1938) and Macdonald (1938). The area to the west was mapped by Kresz and Zayachivsky (1987), to the east by Amukun (1984), and to the south by Coates (1968). The map area is covered by aeromagnetic Maps 2150G Geraldton (ODM–GSC 1962a), 2151G Longlac (ODM–GSC 1962b), 2160G Pagwachuan Lake (ODM–GSC 1962c), and 2161G Castlebar Lake (ODM–GSC 1962d). Most of the map area is part of the eastern Beardmore–Geraldton Metavolcanic–Metasedimentary Belt (Mackasey 1970) and is situated within the eastern Wabigoon Subprovince, while the southeastern part is within the northern Quetico Subprovince. The supracrustal rocks consist of metavolcanics and clastic metasediments. In Daley Township, several felsic to intermediate volcaniclastic units occur within mafic metavolcanics.

SUPRACRUSTAL ROCKS

Kresz and Zayachivsky (1987) have informally subdivided the supracrustal rocks into the northern, central, and southern volcanic units and the intervening northern, central, and southern sedimentary units. These units are laterally continuous into the Seagram Lake area (Figure 25.2) with the exception of the northern sedimentary unit in the Northern Long Lake area that extends into Bickle Township.

The northern volcanic unit (Figure 25.2), metamorphosed to hornblende schists, consists of pillowed basalts with interbedded intermediate to felsic, heterolithic, lapilli–tuff and tuff–breccia.

The southern part of the central volcanic unit (Figure 25.2) consists largely of massive amygdaloidal basalt flows, whereas the northern part comprises mafic ash and plagioclase crystal tuff, and heterolithic lapilli–tuff and tuff–breccia.

The southern volcanic unit consists of pillowed basalt flows metamorphosed to hornblende schist.

Medium– to coarse–grained mesocratic synvolcanic gabbro dikes and sills intrude the volcanic units.

The southern sedimentary unit is continuous throughout the entire map area (Figure 25.2), while the central sedimentary unit is only exposed in Daley Township.

The central sedimentary unit consists of fine–grained turbidites that develop a gneissic texture where they terminate in a granitic intrusion.

The southern sedimentary unit (Figure 25.2) consists of conglomerate, well–bedded massive to graded quartzofeldspathic arenite and wacke that are characteristic of the resedimented associations found in submarine fans (cf. Walker 1984). Centimetre to decimetre thick bands of magnetite iron formation intercalated with wacke, siltstone or arenite appear to have lateral continuity (ODM–GSC 1962a, 1962c). In the northwestern part of Seagram Lake, quartz arenite to quartz–rich arkose is associated with polymictic conglomerate. This polymictic conglomerate is found in several places along the northern part of the southern sedimentary unit. The southern part of the southern sedimentary unit consists of a monotonous sequence of locally garnetiferous wacke and siltstone.

South of McKay Lake, the sediments have been metamorphosed to coarse–grained mica schist and paragneiss with abundant granitic leucosome layers and form part of the Quetico sedimentary terrane (Figure 25.2). One northeast–trending band of iron formation has been found in coarse mica schist south of McKay Lake (Figure 25.2).

INTRUSIVE ROCKS

Within the volcanics, mafic intrusive rocks are typically represented by layer–parallel sills or dikes of mesocratic medium– to coarse–grained gabbro believed to be the intrusive equivalents of the mafic volcanics.

Mafic to ultramafic rocks are found as lenticular bodies associated with the southern sedimentary unit. These rocks consist of coarse–grained pyroxenite, pyroxene–phyric gabbro, medium–grained gabbro, and plagioclase–rich gabbro commonly found within a single lenticular body as a layered sequence. The discontinuous nature of these small bodies suggests they represent a dismembered layered sequence.

Quartz–feldspar and feldspar porphyry dikes and fine–grained aphyric felsic dikes are mainly found near Rockyshore Lake (Figure 25.2).

An irregular, metamorphosed granitic body within the central volcanic unit is composed mainly of diorite and quartz diorite intruded by tonalite and trondhjemite.

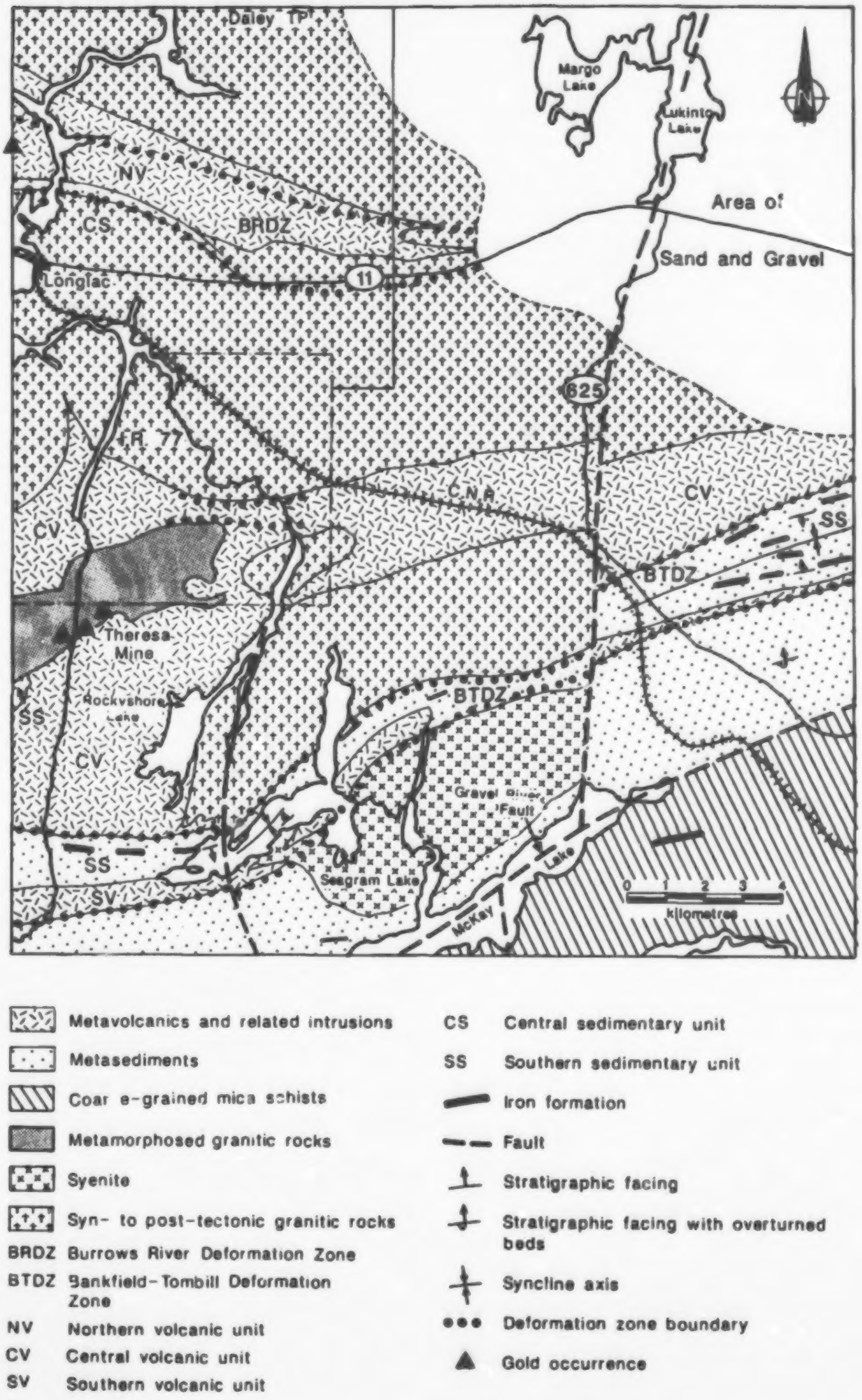
Daley TP
Margo Lake
Lukinto Lake
N
Area of Sand and Gravel
NV
BRDZ
CS
Longlac
11
625
TR. 77
C.N.R.
CV
SS
BTDZ
Theresa Mine
Rockyshore Lake
CV
SS
BTDZ
Gravel River Fault
SS
SV
Seagram Lake
McKay Lake
0 1 2 3 4
kilometres
Metavolcanics and related intrusions
Metasediments
Coarse-grained mica schists
Metamorphosed granitic rocks
Syenite
Syn- to post-tectonic granitic rocks
BRDZ Burrows River Deformation Zone
BTDZ Bankfield-Tombill Deformation Zone
NV Northern volcanic unit
CV Central volcanic unit
SV Southern volcanic unit
CS Central sedimentary unit
SS Southern sedimentary unit
Iron formation
Fault
Stratigraphic facing
Stratigraphic facing with overturned beds
Syncline axis
Deformation zone boundary
Gold occurrence

Figure 25.2. *Geological map of the Seagram Lake area.*

North of McKay Lake, an elliptical intrusion of pink syenite contains rafts of supracrustal rocks. The syenite, dominated by alkali feldspar, contains various amounts of hornblende, biotite and magnetite, and is characterized by a strong magnetic anomaly (ODM–GSC 1962c). Around Seagram Lake (Figure 25.2), the supracrustal rocks have been injected by numerous veinlets and dikes of syenite and in places alkali feldspar has grown in clots. The syenitic stock has foliated margins.

Four massive to foliated granodiorite and quartz monzonite intrusions occur within the map area.

Numerous north–, northwest–, and northeast–trending diabase dikes, some locally plagioclase porphyritic, crosscut all Archean rocks. Crosscutting relationships among the diabase dikes have not been observed. One north–trending diabase dike has a high olivine phenocryst content.

Several small unmetamorphosed lamprophyre dikes and a carbonatized mica peridotite dike were found in the map area.

STRUCTURE AND METAMORPHISM

The overall structure of the map area is similar to that of the Northern Long Lake area (Kresz and Zayachivsky 1987) consisting of east–trending, steeply dipping metavolcanic and metasedimentary units that characterize the Beardmore–Geraldton Belt (Pye *et al.* 1966).

Reliable stratigraphic facing indicators have been found within graded turbidite sequences of the southern sedimentary unit. In the southern part of the southern sedimentary unit, north–facing beds have been overturned and have steep southerly dips. Opposing stratigraphic tops within the northern part of the southern sedimentary unit indicate that it is, at least in part, folded into a syncline (Figure 25.2).

Regional structural studies by Williams (1987) indicate that the Beardmore–Geraldton Belt and the northern part of the Quetico sedimentary terrane is an assemblage of generally north–facing supracrustal lithologies.

Two regional scale east–trending ductile shear zones (BRDZ and BTDZ, Figure 25.2) exhibiting dextral senses of displacement, representing eastward extensions of gold–bearing structures in the Geraldton area (Kresz and Zayachivsky 1987, in preparation), were traced into the map area. The southernmost deformation zone (BTDZ, Figure 25.2), associated with the east–trending Bankfield–Tombill Fault, continues eastward through Seagram Lake parallel to the northern part of the southern sedimentary unit. The Burrows River Deformation Zone (BRDZ, Figure 25.2) is parallel to and within the northern volcanic unit. A third deformation zone occurs on Longlac Indian Reserve 77 and is parallel to the northern part of the central volcanic unit. These are zones of high strain characterized by the presence of conspicuous linear fabric elements in rocks having a well–developed schistosity, disrupted layering, transposed bedding and mineral veins, and asymmetric folds. These high strain zones range from 1 to 3 km in width. Extensional and mineral lineations within the three high strain zones plunge westward at moderate to steep angles. In addition to highly strained rocks, the Bankfield–Tombill Deformation Zone (BTDZ, Figure 25.2) also has large–scale mappable folds. The presence of numerous discontinuous mafic to ultramafic bodies which outcrop over a distance of at least 70 km suggests considerable movement along the Bankfield–Tombill Fault. At Seagram Lake, the presence of mature quartz–rich arenites with polymictic orthoconglomerates associated with turbidites suggests possible tectonic imbrication along the Bankfield–Tombill Fault.

The Gravel River Fault (Williams 1987) underlies McKay Lake. The abrupt transition from fine–grained feldspathic wacke north of McKay Lake to coarse–grained mica schist and gneiss injected with granites south of the lake suggests that McKay Lake is underlain by a fault along which some degree of vertical motion has taken place. The southern side of the lake has been uplifted relative to the northern side.

Several alkalic complexes including the Port Coldwell, Killala Lake, and Chipman Lake alkalic complexes, as well as several diatremes (Sage 1985) are aligned along a pronounced regional north–trending lineament that passes through the map area. The lineament is marked by a string of lakes and extensive sand deposits.

The supracrustal rocks within the map area have been metamorphosed to upper greenschist to amphibolite conditions. Metamorphic grades are highest within the northern volcanic unit and south of McKay Lake where the sediments have been subjected to the initial stages of migmatization. Retrograde metamorphism producing chlorite schist appears to have taken place within high strain zones.

Areas of metasomatism are characterized by the presence of garnet, biotite, alkali feldspar, sulphides, as well as zones of silicification and carbonatization. These occur near discrete, ductile shear zones and in association with brittle fractures.

ECONOMIC GEOLOGY

GOLD

The map area lies east of the Geraldton gold camp. Within the map area, the Theresa Mine (Figure 25.2) produced 4785 ounces of gold between 1935 and 1955 (Mason and McConnell 1982). The mine is located near the southern contact of a metamorphosed dioritic to tonalitic intrusion with mafic metavolcanics. Gold mineralization is in quartz and quartz–tourmaline veins within a discrete northeast–trending shear zone that parallels the southern contact of the intrusion with the volcanics. A grab sample of quartz containing pyrite and minor chalcopyrite from the dump at the western shaft contained 93.7 ppm gold (analysis by the Geoscience Laboratories, Ontario Geological Survey, Toronto). A grab sample of quartz–tourmaline vein material crosscut by secondary glassy quartz with minor chalcopyrite obtained from a trench near the central (main) shaft assayed 20.3 ppm gold (analysis by the Geoscience Laboratories, Ontario Geological Survey, Toronto). At the eastern shaft, discontinuous quartz veins with minor pyrite occur along a sheared contact between diorite and feldspar porphyry. A grab sample of quartz vein material assayed 77.1 ppm gold (analysis by the Geoscience Laboratories, Ontario Geological Survey, Toronto).

Two ductile shear zones (BRDZ and BTDZ, Figure 25.2) provide a structural control for gold mineralization (Kresz and Zayachivsky 1987). The Burrows River Deformation Zone (BRDZ) (Kresz and Zayachivsky, in preparation) in Daley Township is characterized by strongly deformed mafic to felsic volcanics which host small quartz veins, some of which carry minor chalcopyrite and rare molybdenite. The Bankfield–Tombill Deformation Zone (BTDZ) crosses the entire map area from west to east and is confined to the southern sedimentary unit and southern volcanic unit (Figure 25.2). Numerous gold occurrences are present along the BTDZ at Geraldton (Horwood and Pye 1955) and the Northern Long Lake area (Kresz and Zayachivsky 1987). Within the present map area, no known gold showings occur along the BTDZ, although small discrete shears with quartz veining and disseminated sulphides were noted by the field party in the Seagram–Little McKay Lakes area and east of Highway 625. Within the BTDZ, a zone of carbonatization and silicification with disseminated sulphides characterizes a contact of the southern sedimentary unit with the southern volcanic unit (Figure 25.2). The zone is up to 100 m wide and extends eastward from Seagram Lake through the map area.

SUGGESTIONS FOR MINERAL EXPLORATION

Two regional scale deformation zones, the Burrows River Deformation Zone and the Bankfield–Tombill Deformation Zone, described previously in the Northern Long Lake area (Kresz and Zayachivsky 1987, in preparation) extend into the present map area. They should be explored for gold mineralization.

Gold mineralization was observed to be associated with sulphide replacement of iron formation in the Northern Long Lake area (Kresz and Zayachivsky, in preparation) and at Geraldton (Macdonald 1983). The iron formations in the present map area should be investigated for sulphide replacement of magnetite.

Areas of hornblende schist locally rich in sulphides occurring along the Trans–Canada gas pipeline right–of–way north of Longlac warrant further attention.

Massive to porphyritic syenite at the eastern end of Seagram Lake and the large masses of homogeneous massive granodiorite in the map area may have potential for building stone.

ACKNOWLEDGMENT

Part of the Longlac Indian Reserve No. 77 lies in the present map area. The authors express their appreciation for permission to map on the reserve.

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26. Project Number 87–16. Alkalic Rocks of the Thunder Bay Area

M.W. Carter

Geologist, Precambrian Geology Section, Ontario Geological Survey, Toronto.

INTRODUCTION

This report summarizes the results of the field work of the second year of a regional study of the alkalic (shoshonitic) extrusive and intrusive rocks present in the townships of Forbes, Conmee, Goldie, Horne, Blackwell, Laurie, and parts of Conacher and Duckworth, in the Shebandowan Belt of the Abitibi Subprovince west of Thunder Bay (Figure 26.1). Six weeks were spent in the summer of 1988 in various parts of the area. The field work consisted of detailed examinations of selected areas in order to study stratigraphic, lithologic, and structural features; and to collect additional rock samples for mineralogical, petrological, and geochemical investigations. Detailed mapping was conducted along Lower Shebandowan Lake, and to the south and east of the lake where current logging operations in Conacher and Duckworth Townships were expected to expose Timiskaming–type rocks previously mapped by Morin (1973).

The purpose of the project is to clarify ideas on the nature of the Timiskaming–type rocks; and the environment of deposition and emplacement of alkalic (shoshonitic) rocks in the area. The alkalic (shoshonitic) rocks referred to here are those proposed by Joplin (1968) as forming the shoshonite association and which have been systematized on a potash–silica plot by Mackenzie and Chappell (1972) and Brooks *et al.* (1982). They are highly potassic rocks, extrusive members of which form the mafic to felsic series: absarokite – shoshonite – latite – toscanite. Joplin (1968) showed that these rocks contain higher potash concentrations than the potash and soda members of the alkali basalt suite; although some members of the shoshonite and alkali basalt suites show some chemical similarities.

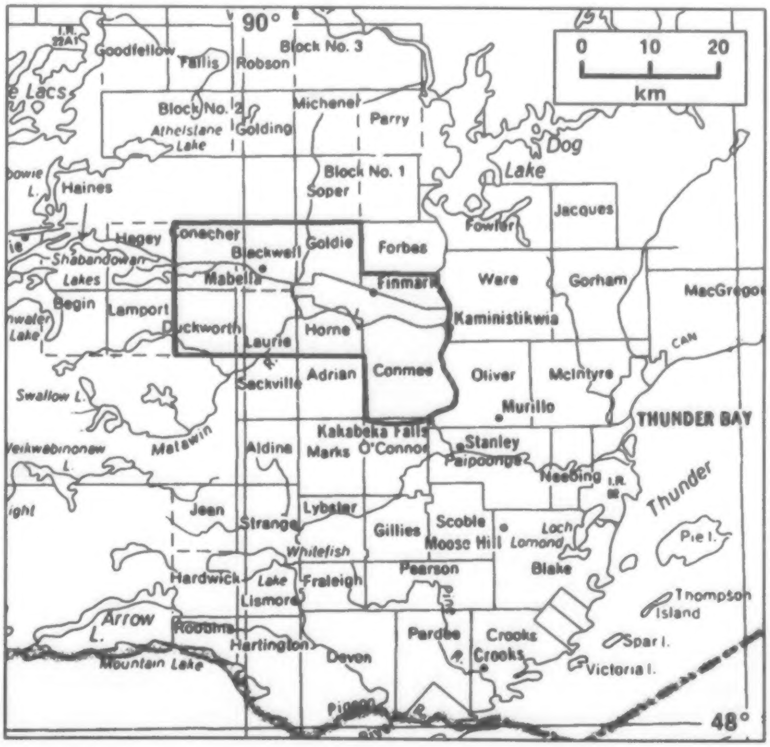
90°
48°
0 10 20
km
Goodfellow
Fallis
Robson
Block No. 3
Block No. 2
Athelstane Lake
Golding
Michener
Parry
Dog Lake
Block No. 1
Soper
Haines
Conacher
Blackwell
Goldie
Forbes
Fowler
Jacques
Hagey
Shebandowan Lakes
Mabella
Finmark
Ware
Gorham
MacGregor
Begin
Lamport
Duckworth
Laurie
Horne
Kaministikwia
Swallow L.
Sackville
Adrian
Conmee
Oliver
McIntyre
Murillo
THUNDER BAY
Matawin
Kakabeka Falls
Aldina
Marks
O'Connor
Stanley
Paipoonge
Neebing
Thunder
Jean
Strange
Lybster
Gillies
Scoble
Moose Hill
Loch Lomond
Pie I.
Whitefish Lake
Hardwick
Fraleigh
Pearson
Blake
Lismore
Thompson Island
Arrow L.
Robbins
Hartington
Pardee
Crooks
Spar I.
Devon
Victoria I.
Mountain Lake
Pigeon

Figure 26.1. *Location map of study area, District of Thunder Bay.*

Lamprophyric intrusive equivalents are referred to as minettes, kersantites, vogesites, and spessartites (Joplin 1968; Middlemost 1985).

MINERAL EXPLORATION

Mineral exploration was being actively carried out during the summer by Inco Gold Company Limited in the area underlain by alkalic breccia and a high-level quartz-monzonite-diorite stock in Conmee Township; in areas underlain by Timiskaming-type alkalic metavolcanic rocks and metasediments in Conacher and Duckworth townships; and in an area underlain by Keewatin-type calc-alkalic and alkalic metavolcanics in Laurie Township. Noranda Exploration Company Limited was carrying out exploration work for gold in central Conacher Township in Keewatin-type rocks and in Blackwell Township.

GENERAL GEOLOGY

The general geology of the study area, which straddles the Quetico-Abitibi (Shebandowan Belt Section) Subprovince boundary, has been described previously (Carter 1987a). During the 1988 season, the study area was extended westward into Conacher Township where the area south of Lower Shebandowan Lake was mapped.

The results of this summer's work confirm the occurrence of alkalic (shoshonitic) volcanic rocks in two areas in the upper part of an emergent Keewatin-type volcanic sequence where the alkalic (shoshonitic) rocks are interlayered with calc-alkalic and potassium-rich calc-alkalic rocks. The alkalic (shoshonitic) rocks also occur in the Timiskaming-type sequence in two sub-environments: a) as two volcanic centres comprising vent and proximal facies complexes in proximity to a bounding fault of a graben structure in a continental alluvial-fan-fluvial environment with associated flows, pyroclastic flows, and lamprophyre dikes in a northern belt; and b) in a suggested near-shore continental margin-type sedimentary-volcanic environment, as flows and pyroclastics in a southern belt (Carter 1987a).

In the upper part of the Keewatin-type sequence in southwestern Duckworth Township, a 3 km northeast-trending section was studied leading northeast from Gold Creek to an area in southwestern Laurie Township studied previously (Carter 1987b). This sequence consists of grey and whitish-grey rhyolitic flows and pyroclastic rocks interlayered with, and passing upward into, mafic and intermediate alkalic (shoshonitic) rocks which are dark mauve and brick-red respectively. No Timiskaming-type sediments were found interstratified with these rocks, and there is no reason to consider these rocks as belonging to the Timiskaming-type sequence. Also, at outcrops in northeastern and central Conmee Township, tholeiitic, calc-alkalic, and shoshonitic rocks as defined earlier, were seen in contact. These contacts appear to the writer to be conformable and suggest that these shoshonitic rocks are part of the Keewatin-type komatiitic, tholeiitic, and calc-alkalic rock sequence. Because of these observations, these shoshonitic rocks, which lithologically, petrographically, and on the basis of chemical data so far obtained, are identical to those observed interlayered with the later Timiskaming-type rocks described below, are grouped as part of the earlier Keewatin-type rocks.

The northern belt of Timiskaming-type rocks exposed in Blackwell Township straddles the Keewatin-Quetico Subprovince boundary. Quetico-type metasedimentary clasts are absent in the polymictic conglomerates of this belt, but such rocks would be expected if an upland, positive, pre-Timiskaming scarp block existed to the north. It is therefore suggested that the Timiskaming-type rocks extend northward beyond the Keewatin-Quetico Subprovince boundary rather than being confined by it as a northern boundary to the graben. In contrast, the polymictic conglomerates at the southern boundary of this belt contain clasts of the Keewatin-type rocks exposed immediately to the south. It is therefore suggested that the northern belt of this Timiskaming-type sequence is probably a graben structure (Frostic and Reid 1987) with a boundary fault forming its southern border. These polymictic conglomerates together with interlayered arkoses, wackes, and mudstones exposed at the southern boundary are interpreted by the author as an alluvial fan sequence (Rust and Koster 1984) with a southern Keewatin-type provenance. These conglomeratic rocks are unpigmented, grey and green, white-weathering rocks containing jasper clasts. The arkoses, wackes, and mudstones are also unpigmented. The significance of using the presence or absence of jasper clasts in distinguishing Timiskaming-type conglomerates from Timiskaming-type tuff breccias (carrying both angular and rounded clasts), used empirically previously by the author, can now be understood. These fragmental rocks are of different provenance: the jasper clasts are derived from the Keewatin-type rocks and are present in the Timiskaming-type conglomerates, whereas they are absent in the Timiskaming-type tuff breccias and pyroclastic debris flows, these being of direct volcanic origin.

Red, red-brown, and mottled red and green fragmental rocks referred to as oligomictic conglomerates by Morin (1973) and as breccio-conglomerates (Shegelski 1980; Brown 1985) are considered by this author to be alkalic (shoshonitic) tuff breccias and pyroclastic debris flows (lahars) of the vent-proximal facies of a volcanic centre environment. These centres border, and are immediately north of, the southern boundary fault of the graben structure extending from Conacher Township in the west, to Ware Township to the east where identical rocks and associations were observed at Strawberry Hill on Highway 102. The rocks consist of angular and rounded clasts of alkalic (shoshonitic) metavolcanics and minor mafic metavolcanics that are well exposed along the Inco Limited mine road south and east of Lower Shebandowan Lake. South of the lake, the breccias are associated with hornblende and hornblende–feldspar porphyry bodies, some of which are intrusive. This combination of tuff breccia, subvolcanic intrusives, and flows forming clearly defined areas, suggest that they represent a volcanic centre. The rocks to the east of the lake are similar, but no flows or subvolcanic intrusives were observed in the area mapped. This eastern area is also interpreted as a Timiskaming–type volcanic centre.

The association of red pigmentation due to hematization and high potassium content is a notable characteristic of these rocks and suggests a significant temporal–lithogeochemical association. Increased oxidation of volcanic rocks of a magmatic suite in the more evolved members of the suite has been described by Rittmann (1973). This also explains the association of high potassium content and red colour so obvious in the latites and toscanites of the area, as well as in the minettes. Future work will evaluate this association.

The intervening area between these east–northeast–trending centres along the central part of the south shore of Lower Shebandowan Lake is occupied by Timiskaming–type sedimentary rocks containing coarse cobble and boulder polymictic conglomerate interlayered with wacke–siltstone and mudstone of the alluvial fan sequence. These rocks are folded about arcuate convex–north axes. South of this Timiskaming–type sequence is a Keewatin–type sequence consisting of spinifex–textured komatiitic flows interlayered with tholeiitic mafic metavolcanics and calc–alkalic pillowed mafic to felsic metavolcanics. The map pattern indicates that these rocks trend east–west. During the 1988 season, the Timiskaming–Keewatin boundary was located in two areas, with only 1 m of intervening cover, but the two sequences were not observed in actual contact. The trace of the Timiskaming–Keewatin boundary is sinuous and trends east–northeast.

The second area where Timiskaming–type alkalic (shoshonitic) metavolcanic rocks occur is in a southern belt (Carter 1987a) consisting of mudstone, wacke, arkose, and conglomerate with laminated magnetite–jasper, magnetite–clastic metasediment ironstone. The boundary of this sequence with the Keewatin–type sequence is sinuous and irregular. The ironstone unit extends from west–central Horne Township to Lamport Township – a distance of about 27 km. The ironstone has been described as a true taconite (Halet 1972) and the extensive linear form and rock association suggests a near–shore continental type of marine environment for deposition of ironstone similar to the Superior Type of banded ironstone of Gross (1965), Dimroth (1979), and Stanton (1972). This suggests that the Timiskaming–type sequence in this southern belt is not a fanglomerate–alluvial–fan–fluvial sequence as in the north. No major volcanic centres similar to those in the northern belt have been located, but red alkalic flows and pyroclastics occur interstratified with the sediments. The occurrence of hematite–stained rocks in the volcanic centres of the northern belt and red hematized tuffs and flows in the southern belt suggests that the iron for the ironstone units in the southern belt is exhalatively–derived from the tuffaceous alkalic Timiskaming–type centres to the north. A suggested source for the iron of Superior Type ironstone, which is restricted in time to this general stratigraphic level, may thereby be explained, avoiding the transportation problem of the continental erosion theory (Stanton 1972).

STRUCTURAL GEOLOGY

The major structural features of the study area were described in (Carter (1987a), where it was noted that the Timiskaming–type rocks occur in a northern and southern belt.

In the northern belt, during the 1988 season, contacts between the Keewatin–type and Timiskaming–type rocks were closely examined. In Conacher Township, slickensides on Keewatin–type rocks at the contact indicate a downthrow to the north of the Timiskaming–type rocks on a faulted contact with the Keewatin–type rocks. The generally easterly trend of the Timiskaming–type clastic rocks of alluvial–fan–fluvial–type observed in the study area, the occurrence of normal faulting at the Timiskaming–Keewatin contact suggests a graben structure with a faulted Timiskaming–Keewatin contact for the southern boundary, and an unconformable Timiskaming versus Keewatin–Quetico contact for its northern boundary. The association with alkalic (shoshonitic) volcanism suggests, on the basis of the Phanerozoic plate–tectonic model, that the rocks of the northern Timiskaming–type belt represent a possible failed–arm graben structure of an intracontinental rift zone representing incipient rifting (Selley 1975; Park 1983) caused by domal uplift.

Within the conglomerates along the Inco Limited mine road in Conacher Township considerable shearing was observed indicating that tectonic activity was also active after deposition of the Timiskaming–type rocks.

In the southern belt at Middle Falls on the Matawin River in Laurie Township, a faulted contact was observed between the Timiskaming–type and Keewatin–type rocks with breccia or conglomerate developed. No conglomerate was observed in the Timiskaming–type sediments nearby and the breccia is interpreted as a fault breccia associated with a northeast–trending fault mapped previously in the area (Carter 1987b). The general irregular contact of the Timiskaming–type rocks with the underlying Keewatin–type rocks in the study area suggests an unconformable contact, hence this basin is not a graben, but a continental shelf zone.

The occurrence of similar shoshonitic rocks which appear to be comagmatic in the Keewatin-type rocks which represent a tectonic environment of compression; and in the later Timiskaming-type rocks which are considered by the author to have been deposited during a period of extension tectonics requires further study. Specifically, further chemical study of the shoshonitic rocks of the two rock suites will be carried out to determine whether they are petrogenetically distinct.

ECONOMIC GEOLOGY

The economic geology of the area covered by Goldie and Horne, Forbes and Conmee, and Blackwell and Laurie townships has been previously described (Carter 1984, 1985a, 1986a) and is not repeated here.

In the northern Timiskaming belt, in the area south and east of Lower Shebandowan Lake (Figure 26.2) shears have been observed in the Timiskam-

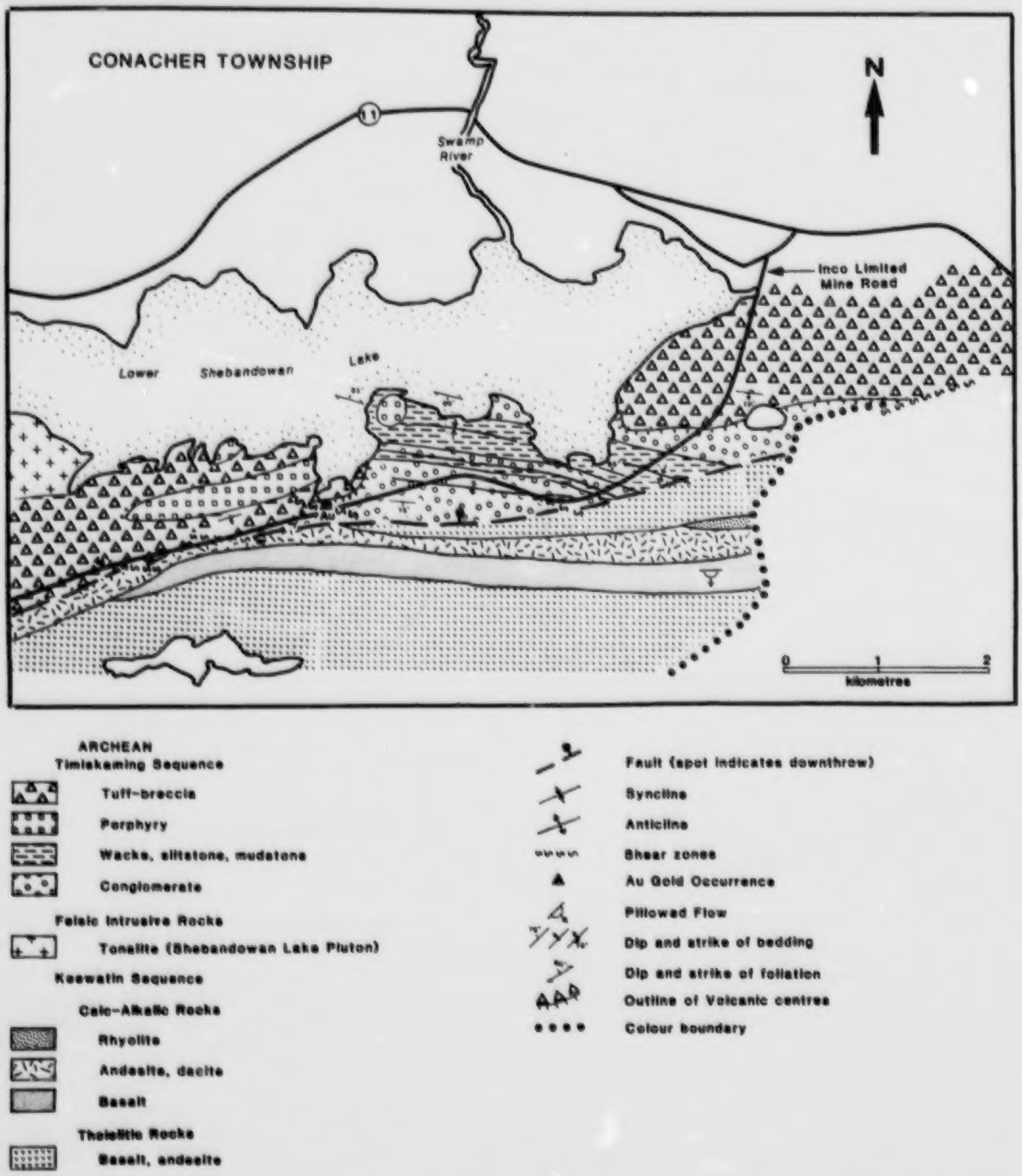
CONACHER TOWNSHIP
N
11
Swamp River
Inco Limited Mine Road
Lower Shebandowan Lake
0
1
2
kilometres
ARCHEAN
Timiskaming Sequence
Tuff-breccia
Porphyry
Wacke, siltstone, mudstone
Conglomerate
Felsic Intrusive Rocks
Tonalite (Shebandowan Lake Pluton)
Keewatin Sequence
Calc-Alkalic Rocks
Rhyolite
Andesite, dacite
Basalt
Tholeiitic Rocks
Basalt, andesite
Fault (spot indicates downthrow)
Syncline
Anticline
Shear zones
Au Gold Occurrence
Pillowed Flow
Dip and strike of bedding
Dip and strike of foliation
Outline of Volcanic centres
Colour boundary

Figure 26.2. *Geological sketch map of the southern shore of Lower Shebandowan Lake showing location of volcanic centres, shear zones, and gold occurrences.*

ing-type conglomerates, and at the Timiskaming–Keewatin boundary, trending on average 100° with a steep dip of 70° to 80° north, south, or vertical. A strong shear trending 070° with a steep dip of 85° northwest, and a mineral lineation which plunges 70° to the west-southwest, were observed in the Timiskaming-type alkalic tuff breccia in the eastern volcanic centre described above. During mapping in 1988, in Conacher Township, grab samples were collected from shears in the Timiskaming-type metasediments and metavolcanics. In east-southeast-trending shears, a grab sample taken from a malachite-stained quartz vein 3 cm wide trending 095° which was emplaced in a 2 m wide band of polymictic Timiskaming-type conglomerate mineralized with nodules of pyrite or marcasite, assayed 0.02 ounce gold per ton (Geoscience Laboratories, Ontario Geological Survey, Toronto). Samples from other shear zones yielded <0.01 ounce gold per ton (Geoscience Laboratories, Ontario Geological Survey, Toronto).

SUGGESTIONS TO PROSPECTORS

On the basis of the model put forward for the deposition of Timiskaming-type rocks in the northern belt, gold exploration for syngenetic and epigenetic deposits can be recommended.

In the case of syngenetic deposits in the Timiskaming-type rocks, mapping has shown that along the southern part of the Timiskaming–Keewatin boundary in the northern belt, occurrences of gold are found in Keewatin-type rocks: e.g. in northeastern Conmee Township and southeastern Dawson Road Lots at Sistonens Corners (Carter 1985a, 1986b); at the Bylund and West occurrences in the south-central part of the Dawson Road Lots (Carter 1984, 1985b); and at the Hayne and Kaspar Occurrences in northeastern Laurie and southeastern Blackwell townships respectively (Carter 1986a, 1987b, 1987c). The clast population of the Timiskaming-type rocks indicate derivation of the sediments from the Keewatin-type rocks to the south. If these deposits were formed prior to the formation of the Timiskaming-type rocks, the possibility exists of paleochannels in the alluvial fan deposits and for detrital gold occurrences in paleoplacers which occur in such deposits (Gross 1968; Johnson 1972a, 1972b, 1973; Minter 1981; Pretorius 1974). Similar studies should be carried out in the conglomerates of the southern belt. However, because of the immaturity of the sediments, the potential for the discovery of auriferous paleoplacers is not considered high.

For epigenetic deposits in the Timiskaming-type rocks, attention should be paid to east-southeast- and east-northeast-trending shear zones (Figure 26.2) cutting Timiskaming-type metavolcanic and metasedimentary rocks, especially the conglomerates in Conacher Township. One of the shear zones in the conglomerates is mineralized with gold (Figure 26.2), as was determined during the current survey by assay by the Geoscience Laboratories, Ontario Geological Survey, Toronto. The best gold prospects in these shears are where pyrite or copper minerals occur. Specifically, the mineralized auriferous shear shown on Figure 26.2, and located on the Inco Limited mine road, should be prospected further. Although shears were not well developed in the Timiskaming-type alkalic tuff breccia volcanic centres, joints in the centre to the southwest show 2 cm wide alteration zones suggestive of primary fumarolic zones. Two shears were mapped in the eastern metavolcanic centre and an assay sample from the strong shear near the eastern part of the centre assayed <0.01 ounce gold per ton. These centres, which are composed of coarse tuff breccia, should be prospected for signs of hydrothermal activity. The occurrence of coarse breccias is favourable for providing depositional sites for mineralization. The two Timiskaming-type alkalic volcanic centres are outlined in Figure 26.2. Prospecting for gold in the Timiskaming-type ironstone of the southern belt, where it is cut by quartz veins or mineralized with pyrite and arsenopyrite, has already been recommended (Carter 1987b).

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Abitibi Subprovince

27. Abitibi Subprovince Studies

R.H. Sutcliffe

Geologist, Precambrian Geology Section, Ontario Geological Survey, Toronto.

INTRODUCTION

The Abitibi Greenstone Belt is one of the most extensive exposures of late Archean supracrustal rocks in the world and accounts for a significant proportion of Ontario's mineral production. Previous geological mapping and investigations have produced an understanding of the lithological framework of the Abitibi Belt but a model for the tectonic framework and evolution of the Belt is not well developed. The Precambrian Geology Section of the Ontario Geological Survey has established a working group to carry out a comprehensive geological study of the Abitibi Belt. This group will continue systematic mapping of the Abitibi Belt and develop a model to describe its evolution.

Supracrustal rocks of the Abitibi Belt have been subdivided into dominantly komatiitic, tholeiitic, calc–alkaline, alkaline, and sedimentary lithostatigraphic units (Jensen and Langford 1985), which have been thought to represent a stratigraphic continuum. It is now recognized, on the basis of geochronological studies (Corfu *et al.*, in press, Marmont and Corfu 1988) and structural studies (Toogood and Hodgson 1985, Hamilton 1986), that structural discontinuities form some boundaries between repeated stratigraphic sequences or out–of–sequence supracrustal packages. A major aim of geological mapping in the Abitibi program is to elucidate the relationships within and between these stratigraphic packages or lithostructural domains. In view of the significance of these domain boundaries in localizing mineralization, this goal has important implications for mineral exploration.

CURRENT FIELD WORK

During 1988, several field studies within the Abitibi program were carried out. These focused on detailed mapping and structure of supracrustal rocks, particularly in areas of mineralization; mapping and petrological studies of plutonic rocks; and regional geophysical studies.

D.W. Piroshco and K. Kettles (this volume) completed a two–year mapping project in Whitney and Tisdale townships. In 1988, field work was concentrated on establishing the timing of structural and mineralization events in the area north of the Destor–Porcupine Deformation Zone. Preliminary results suggest that two ages of gold–mineralized quartz veins are present. These veins can be related to two distinct late deformational events.

S.L. Jackson (this voloume) initiated a detailed mapping project in the McVittie Township area east of Kirkland Lake. His project has the aim of determining the structure and stratigraphy within and between lithostructural domains in this economically important area of gold mineralization. The work has focused on timing of structural events in the vicinity of the Kirkland Lake–Larder Lake Deformation Zone. It has also provided new evidence for a depositional contact between the Kinojevis and Timiskaming Groups. Preliminary evidence also points to a previously unreported zone of deformation separating the Kinojevis and Blake River Groups.

Granitoid rocks constitute a significant proportion of the Abitibi Subprovince and are an important component in the evolution of the belt. As well, some of these rocks have a close spatial and possibly genetic association with gold deposits. However, limited data currently exist on their nature. A.R. Smith and R.H. Sutcliffe (this volume) initiated mapping and petrological studies of plutonic rocks in the Abitibi Belt to provide data on the nature of magmatism associated with late Archean crustal stabilization. Initial work indicates that both the late tectonic tonalite–granodiorite and alkaline suites are associated with coeval, mantle–derived mafic magmatism. This finding has important implications for understanding the origin of these felsic plutonic rocks. Additional studies, also in progress, will determine the relationships between layered mafic intrusions and mafic volcanic rocks.

Seismic–reflection profiling has provided exciting new geophysical data on the nature of the crust beneath the Abitibi Belt. This research is being carried out in co–operation with G.F. West, Professor, Department of Physics, University of Toronto, and is being coordinated with the Canadian Lithoprobe Program. In late 1987, data was collected along two Abitibi Belt profiles in Ontario. A regional profile was recorded to sixteen seconds (corresponding to approximately 48 km depth) from Lake Abitibi to Catherine Township south of Larder Lake. A detailed profile was recorded to eight seconds in McVittie, Katrine, and Ben Nevis townships.

Preliminary results of this seismic survey were available for the 1988 field season. Geological mapping was carried out in areas where seismic events extrapolate to the surface. The detailed profile indicates a north–dipping seismic reflector projecting to the surface approximately where the Monocle Lake Deformation Zone crops out (*see* Jackson, this volume). The regional profile is dominated by a south–

dipping seismic event, recorded at two to four seconds (approximately 6 to 12 km depth), which is present under most of the section. Field work and further geophysical studies will attempt to discriminate among possible explanations for this event. These may include a basal thrust zone, a basal normal shear zone, and an intrusive contact.

Field work was also carried out in areas of the Abitibi Subprovince which are not part of the main Abitibi Belt. These studies concentrated on establishing the nature and timing of deformation events and the relationship between deformation, alteration, and gold mineralization. J.A. Fyon and B. Hrabi (this volume) completed detailed mapping in the Temagami Greenstone Belt and T.L. Muir (this volume) continued detailed mapping which will form the basis of a synthesis of the Hemlo gold-molybdenum deposit. G.M. Siragusa (this volume) conducted a study of several gold deposits in the Swayze belt. These and continuing studies in the Michipicoten belt near the community of Wawa are reported elsewhere in this volume.

CONCLUDING REMARKS

Initial field work in the Abitibi program has concentrated on aspects of the geology of the Belt which have not been emphasized in previous mapping. A focus of the work has also been along a north–south transect in the eastern part of the Ontario segment of the Abitibi Belt. This transect provides an opportunity to examine the relationships across several lithostructural domains.

Lithological and structural patterns in domains of the Abitibi Belt invite a comparison with modern accretionary terranes. Studies of the structure and origin of discontinuities between domains are essential to understand how these sequences were assembled and their relationships to mineralization. Integration of previous work, new field observations, geochemical data, and geophysical data will provide a framework on which to construct and test an evolutionary model for the Abitibi Greenstone Belt.

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28. Project Number 88–08. Plutonic Rocks of the Abitibi Subprovince

A.R. Smith and R.H. Sutcliffe

Geologists, Precambrian Geology Section, Ontario Geological Survey, Toronto.

INTRODUCTION

This summary presents preliminary results of geological mapping of Archean plutonic rocks in the eastern part of the Ontario segment of the Abitibi Subprovince. During the 1988 field season, regional mapping (1:50 000 scale) was completed on the Abitibi Batholith and the Otto Stock, and detailed mapping (1:15 840 scale) was completed on the Ghost Range Sill. The purpose of this project is to determine the lithological distribution, tectonic setting, and characteristic mineralization of the major intrusions in the Abitibi Greenstone Belt. The current field work is the initial part of a project to examine late Archean magmatic events as they pertain to the evolution of the Abitibi Greenstone Belt.

Jensen and Langford (1985) have described the stratigraphy in the Kirkland Lake area of the Abitibi Greenstone Belt, to which the reader is referred for more detailed information. In this area, several Archean volcanic sequences with associated sediments and plutonic rocks are preserved between major, east–trending fault zones.

ABITIBI BATHOLITH

LOCATION AND ACCESS

The Abitibi Batholith crops out north of Lake Abitibi between Latitudes 48°40′N and 48°58′N, and between Longitudes 79°23′W and 80°03′W (NTS 32D/12 and 13). The batholith is located 50 km east of Matheson and 60 km north–northeast of Kirkland Lake, and covers parts of Bonis, Berry, Sargeant and Steele townships (Figure 28.1). Approximately 15 percent of the batholith lies east of the Ontario border in Desmeloizes Township, Québec.

The batholith is most easily accessed from Lake Abitibi, on which boats may be launched at Ghost River Bay and Eades in Ontario, and at La Reine in Québec. Road access may be gained from the Translimit Road, which extends from Iroquois Falls in Ontario to La Reine in Québec, traversing the northern part of the area mapped in 1988. A network of logging roads extending south of the Translimit Road provides access to the centre of the batholith.

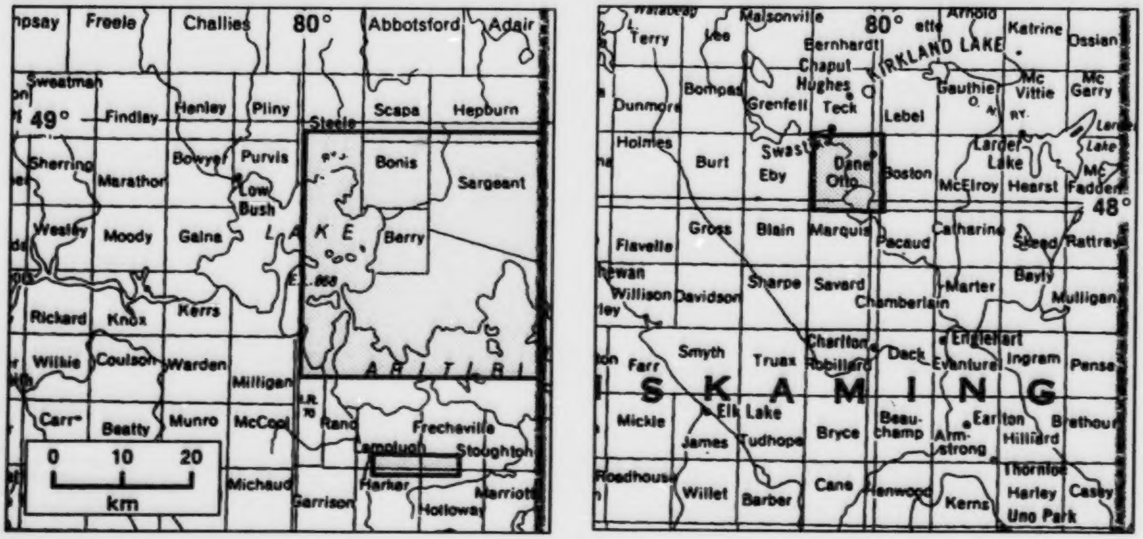

Freele
Challies
80°
Abbotsford
Adair
Sweatman
49°
Findlay
Henley
Pliny
Scapa
Hepburn
Steele
Sherring
Marathon
Bowyer
Purvis
Low Bush
Bonis
Sargeant
Wesley
Moody
Gaine
LAKE
Berry
Rickard
Knox
Kerrs
Wilkie
Coulson
Warden
Milligan
ABITIBI
Carr
Beatty
Munro
McCool
Rand
Frecheville
Lamplugh
Stoughton
Michaud
Garrison
Harker
Marriott
Holloway
0
10
20
km
Terry
Lee
Maisonville
80°
Arnold
Bernhardt
KIRKLAND LAKE
Katrine
Ossian
Chaput–Hughes
Bompas
Grenfell
Teck
Gauthier
Mc Vittie
Mc Garry
Dunmore
Lebel
Holmes
Burt
Swastika
Eby
Dane
Otto
Boston
Larder Lake
McElroy
Hearst
McFadden
48°
Flavelle
Gross
Blain
Marquis
Pacaud
Catharine
Skead
Rattray
Willison
Davidson
Sharpe
Savard
Chamberlain
Marter
Bayly
Mulligan
Farr
Smyth
Truax
Charlton
Robillard
Dack
Englehart
Evanturel
Ingram
Pense
S K A M I N G
Mickle
Elk Lake
James
Tudhope
Bryce
Beauchamp
Armstrong
Earlton
Hilliard
Brethour
Roadhouse
Willet
Barber
Cane
Henwood
Kerns
Thornloe
Harley
Casey
Uno Park

Figure 28.1. *Locations of plutonic rocks mapped in the current project.*

MINERAL EXPLORATION

Exploration interest in the Lake Abitibi area has been primarily for gold. Exploration work has focused on quartz veins hosted in amphibolite grade mafic metavolcanic rocks along the northeastern edge of the Abitibi Batholith. Chromite and asbestos occurrences, hosted in narrow zones of serpentinized ultramafic metavolcanic flows, have received some exploration interest (Kretschmar and Kretschmar 1986). The batholith has undergone little exploration work, and only one gold occurrence has been outlined in the area mapped during this study.

Gold was first discovered in the area in 1906, on Shaft Island, situated west of the batholith. Surface trenching and a 97 foot exploration shaft were used to examine the quartz vein–hosted mineralization. From 1906 to 1925, numerous claims were staked along the shoreline of Northeast Bay to investigate other large quartz veins for gold. The Shaft Island Prospect was resampled in 1933 by P.E. Hopkins (Resident Geologist's Files, Ontario Ministry of Northern Development and Mines, Kirkland Lake), and geological mapping and diamond drilling (24 drillholes, 3502 feet or 1068 m) were completed on the same occurrence by Candore Explorations Limited during 1958 and 1959. Gold values up to 1.2 ounce per ton (41.1 gms) over 9 inches (23 cm) were obtained.

Exploration programs were conducted along the eastern shore of Northeast Bay and on numerous islands within the bay between 1965 and 1986. Companies active in this exploration included West Hill Copper Mines Limited, Canadian Occidental Petroleum Limited, Rio Tinto Canadian Exploration Limited, Cominco Resources International Limited, Asarco Exploration Company of Canada Limited, Gold Island Resources Limited, Silver Sceptre Resources Limited, Del Norte Chrome Corporation, Cream Silver Mines Limited, and Utah Mines Limited. Numerous prospectors also explored in the area during this period.

Airborne magnetic and electromagnetic (VLF) surveys were completed in the majority of exploration programs, with follow-up diamond drilling to test predominantly northeast–trending and east–trending conductors and anomalies. Geophysical responses were obtained from diabase dikes, magnetite–rich mafic and ultramafic metavolcanic units, magnetite–bearing diorite intrusions, and faults. The most recent exploration work was carried out by Golden Trio Minerals Limited, in the vicinity of Shaft Island. A ground electromagnetic survey outlined 32 east–striking conductors, while a ground IP survey detected four anomalies. Despite this abundant exploration activity, economic deposits have not been outlined in the Abitibi Batholith or in its immediate host rocks.

GEOLOGY

Geological mapping of the Abitibi Batholith has been done on a reconnaissance scale (1 inch to 2 miles (1:126 720)) by Baker (1909). The extreme northern part of the batholith, exposed in Bonis and Sargeant townships and in Northeast Bay of Lake Abitibi, was mapped in 1959 and 1960, at a scale of 1 inch to 1/2 mile (1:31 680) (Lumbers 1962, 1963). The southern edge of the batholith was mapped in 1973 at a scale of 1 inch to 1/4 mile (1:15 840) (Jensen 1982a, b). The area is included on ODM Geological Compilation Map 2205 (Pye *et al.* 1971) and on MERQ–OGS Map 2484 (Ministère de l'Énergie et des Ressources, Québec–Ontario Geological Survey 1983).

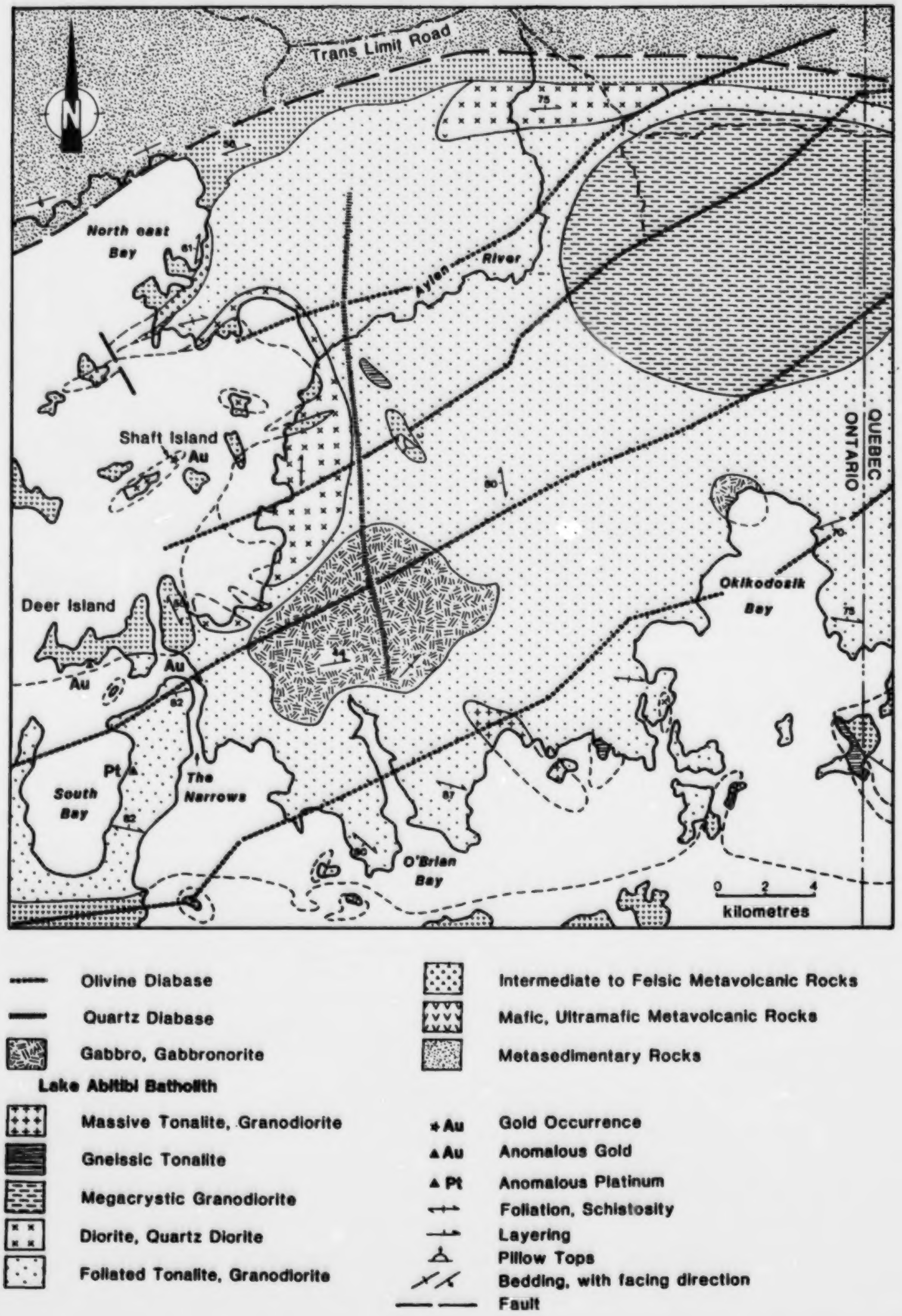
The batholith is approximately circular in shape, extending for 34 km north–south and 50 km east–west (Figure 28.2). It intrudes calc–alkalic metavolcanic rocks of the Hunter Mine Group (Lower Supergroup), and tholeiitic to komatiitic metavolcanic rocks of the Stoughton–Roquemaure Group (Upper Supergroup) (Jensen and Langford 1985). Precise U–Pb geochronology yielded ages of 2713±2 Ma and 2714±2 Ma for calc–alkalic rocks of the Hunter Mine Group and for rhyolite at the base of the mafic–ultramafic Stoughton–Roquemaure Group, respectively (Corfu *et al.*, in press). A porphyritic granodiorite from the northeastern edge of the Abitibi Batholith yielded a younger age (2689 +2.7/–2.3 Ma) than the volcanic rocks (Mortensen 1987).

Calc–alkalic rocks exposed in Northeast Bay and on islands south of MacDougal Point in Lake Abitibi are andesite and dacite flows and rhyolite tuff–breccia. Rocks of the Stoughton–Roquemaure Group, exposed on the mainland north of the batholith and on numerous islands in Lake Abitibi, consist predominantly of magnesium–rich tholeiite basalt flows, with minor peridotite and basaltic komatiite flows. These rocks are highly deformed in close proximity to the batholith, resulting in schistose to gneissic textures, and are of amphibolite metamorphic grade.

A south–facing metasedimentary sequence consisting of meta–greywacke and hornblende schist borders the north–facing Stoughton–Roquemaure Group to the north. This reversal in attitude between metavolcanic and metasedimentary units, along with the high degree of deformation and carbonatization, suggests the contact may be a fault (Lumbers 1962).

North–trending Matachewan dikes (quartz–bearing diabase) cut both the Abitibi Batholith and its host rocks. Northeast–trending, Middle Proterozoic Abitibi (Keweenawan) dikes, consisting of olivine–bearing diabase and gabbro, are the youngest rocks in the map area.

Four separate lithologic/structural phases have been outlined in the batholith by the current mapping, defining it as a composite intrusion. These



N
Trans Limit Road
North east Bay
Aylen River
Shaft Island
Au
Deer Island
Au
Au
Pt
South Bay
The Narrows
O'Brian Bay
Okikodosik Bay
QUEBEC
ONTARIO
0 2 4
kilometres
Olivine Diabase
Quartz Diabase
Gabbro, Gabbronorite
Lake Abitibi Batholith
Massive Tonalite, Granodiorite
Gneissic Tonalite
Megacrystic Granodiorite
Diorite, Quartz Diorite
Foliated Tonalite, Granodiorite
Intermediate to Felsic Metavolcanic Rocks
Mafic, Ultramafic Metavolcanic Rocks
Metasedimentary Rocks
Au Gold Occurrence
Au Anomalous Gold
Pt Anomalous Platinum
Foliation, Schistosity
Layering
Pillow Tops
Bedding, with facing direction
Fault

Figure 28.2. *Generalized geology of the Abitibi Batholith.*

phases, in order of interpreted age relations, are: 1) hornblende diorite to quartz diorite; 2) foliated hornblende–biotite tonalite and granodiorite; 3) massive granodiorite and tonalite; and 4) megacrystic granodiorite.

Hornblende diorite to quartz diorite (Unit 1) typically occur close to the northern and western margins of the batholith and as isolated satellite intrusions within host volcanic rocks. Where foliated and medium grained, the diorite and quartz diorite contain prismatic hornblende and clinopyroxene. Where massive, the diorite and quartz diorite are inequigranular and heterogeneous, with leucocratic and melanocratic segregations and xenoliths of assimilated amphibolitic volcanic rocks. Intrusion breccias with a diorite matrix and hornblendite to amphibolite fragments are present at several localities around the batholith.

Foliated tonalite (Unit 2) occupies the largest part of the batholith. This unit is medium to coarse grained and contains blocky to prismatic hornblende and plagioclase. Tonalite near the outer margin of the intrusion is dominated by hornblende, whereas biotite predominates near its centre. A weak gneissosity, defined by compositional banding of hornblende and plagioclase, is locally present in the tonalite, which displays gradational relations with the diorite to quartz diorite of Unit 1. Narrow fracture and vein networks of tonalite locally occur within diorite, and inclusions of diorite have been noted in tonalite, indicating an intrusive relationship. However, the presence of rare tonalite inclusions in diorite may suggest contemporaneous emplacement of the two phases.

Massive, medium–grained granodiorite (Unit 3) is best exposed in the south central part of the batholith. It is medium to coarse grained, and is characterized by rounded quartz phenocrysts up to 1.2 cm in diameter, euhedral potassic feldspars, and medium–grained biotite and plagioclase. The contact between foliated tonalite (Unit 2) and massive granodiorite (Unit 3) was not observed.

Megacrystic granodiorite (Unit 4) crops out in the northeastern part of the batholith. The overall extent of this unit is poorly constrained due to the scarcity of outcrop in this portion of the map area. The granodiorite is massive to foliated, medium to coarse grained and characterized by the presence of euhedral 1 to 2 cm potassium feldspar megacrysts. This unit contains biotite and hornblende as the predominant mafic phases, and numerous hornblende–rich autoliths or inclusions. Contact relations between this and other units in the batholith were not observed.

The youngest felsic plutonism in the Abitibi Batholith is represented by aplite and leucotonalite dikes, which are common near its outer margin, and crosscut all other granitoid phases.

The current mapping also outlined a previously unreported mafic intrusion, completely contained within the Abitibi Batholith. This intrusion forms an irregularly shaped body, approximately 10 km east–west by 7 km north–south. It comprises an outer zone of hornblende gabbro and hornblende melagabbro, which grades inward to gabbro and gabbronorite in the centre. Altered clinopyroxenite inclusions within gabbro may be autoliths of ultramafic cumulate layers. Cumulate phases include clinopyroxene, orthopyroxene, and plagioclase. Weak modal layering, defined by relative concentrations of pyroxene and plagioclase, were observed to dip steeply inward at the intrusion's edge and more gently inward near its core, suggesting that it is funnel–shaped.

The continuity of the units within this gabbroic intrusion, and its contacts with the granitoid rocks of the batholith, are poorly defined due to the scarcity of outcrop. Numerous, fine–grained tonalite dikes crosscut the gabbroic body, suggesting that some felsic plutonism postdates it.

STRUCTURAL GEOLOGY

The regional lithologic trend in volcanic and sedimentary units is east–northeasterly, to which the long axis of the Abitibi Batholith is approximately parallel. Additional features which parallel this trend include deformation zones and the Middle Proterozoic Abitibi (Keweenawan) dike swarm.

The Abitibi Fault Zone (Lumbers 1962), located north of the batholith, trends east–northeasterly to easterly and is interpreted to mark a thrust fault contact between north–facing metavolcanic rocks and south–facing metasedimentary rocks.

Deformation zones within the batholith and host rocks display two prominent orientations. Northeast– to east–northeast–trending, north–dipping fractures parallel regional structural trends and are the dominant deformation zone orientations. These deformation zones are continuous along strike for tens to hundreds of metres, and range in width from several metres to tens of metres. North– to northwest–trending, northeast–dipping deformation zones are less abundant and smaller. Minor fault offsets often occur in both deformation zone orientations.

ECONOMIC GEOLOGY

Metallic mineral occurrences previously discovered within and in the vicinity of the Abitibi Batholith include gold, copper, chromium and asbestos. In addition, two occurrences of anomalous gold and one occurrence of anomalous platinum were discovered during the present mapping.

Resampling of a gold–copper–zinc showing located on Shaft Island confirmed the presence of substantial gold values in a quartz vein. The vein occupies a northeasterly–striking shear zone within medium–grained diorite in the northern part of the island. It measures 72 m in length and ranges in width from 10 to 40 cm. Blue–black quartz contains pyrite, chalcopyrite, pyrrhotite and an emerald–green mica. A grab sample from the vein exposed in a shallow trench returned an assay value of 44.55 ppm Au (1.29 ounce per ton). Similar vein quartz exists on other islands in the vicinity of Shaft Island.

Anomalous gold values were also returned from mafic rocks in two localities in the western half of the map area. On a small island immediately south of Deer Island, pillowed, amygdaloidal, magnesium–tholeiitic metavolcanics with pillow breccia were found to contain sulphides. Aggregates of pyrite and pyrrhotite form irregular pods and lenses in interpillow spaces. A grab sample from one such sulphide pod returned 350 ppb Au.

An anomalous gold value was also obtained from an east–northeast–trending Abitibi olivine gabbro dike cropping out in The Narrows of Lake Abitibi. A grab sample of coarse–grained, olivine- and magnetite–bearing gabbro with <1 percent pyrrhotite and pyrite returned a value of 50 ppb Au.

An anomalous platinum value was obtained from a north–northwest–trending Archean gabbro dike occurring on the eastern side of South Bay. A grab sample of medium–grained gabbronorite containing <1 percent fine–grained disseminated pyrrhotite and pyrite returned a platinum value of 100 ppb.

Future exploration efforts near the Abitibi Batholith should focus on evaluation of mineralization within deformation zones. The largest and most continuous deformation zones occur in metavolcanic rocks and along the batholith/volcanic rock contact in the Northeast Bay area. Some of these zones may have formed in response to batholith emplacement. Sulphide mineralization often consists of pyrrhotite and pyrite lenses parallel to the strike of the deformation zones. Silicification, epidotization and amphibolitization have all been noted in mineralized deformation zones. Where quartz veins are present in deformation zones, molybdenite and chalcopyrite are present. Detailed geological mapping and prospecting would be useful to evaluate the potential for deformation zone–related gold mineralization in both the host metavolcanic rocks and in the granitoid rocks of the Abitibi Batholith.

Other targets for gold exploration are replacement sulphide mineralization in interpillow material and mineralization in narrow fracture–fillings within metavolcanic rocks in the vicinity of Deer Island. Detailed geological mapping and prospecting could again be used to evaluate the extent of sulphide–mineralized horizons.

Mafic intrusive rocks in the map area are potential host rocks for platinum and/or gold mineralization. Coarse–grained gabbro and olivine diabase dikes with only traces of sulphide mineralization have returned anomalous values of both gold and platinum. The large mafic intrusions in the southwestern part of the Abitibi Batholith should be prospected and mapped in detail, and any sulphide–bearing zones should be tested for platinum group element (PGE) mineralization.

OTTO STOCK

INTRODUCTION

The Otto Stock is a late to posttectonic potassium–rich Archean intrusion situated in Otto Township, 20 km southwest of Kirkland Lake. The intrusion is traversed by Highways 11 and 12.

GEOLOGY

Previous geological mapping in the stock was completed in 1968 (Lovell 1972) and in 1970 (Wolfe and Wright 1971) at a scale of 1 inch to 1/2 mile (1:31 680). A precise zircon (and titanite) U–Pb age of 2680±1 Ma was obtained for the Otto Stock by Corfu *et al.* (in press).

The Otto Stock is one of a series of alkalic intrusions exposed on the south side of the Kirkland Lake–Larder Lake Fault. The contact between the Otto Stock and host volcanic rocks is marked by a lit–par–lit injection gneiss. Porphyritic syenite and locally mafic syenite lenses alternate with almandine–amphibolite facies mafic metavolcanic rocks in the contact aureole.

The Otto Stock is roughly circular, with a 10 km diameter, and is subdivided here into five major lithologic phases (Figure 28.3). Two phases, syenite and porphyritic syenite, comprise 80 percent of the intrusion. Medium–grained syenite occurs in the intrusion's core, while porphyritic syenite, characterized by coarse, euhedral, potassic feldspar crystals, occurs in the outer margin. The third most extensive phase consists of massive quartz syenite, which crops out in the west central part of the intrusion. A mafic syenite, characterized by a high (40 to 50 percent) content of clinopyroxene and biotite, occurs along the northeastern edge of the intrusion.

As a result of the current mapping, a fifth intrusive phase of the Otto Stock has been identified. This is a cumulate–textured mafic to ultramafic rock, which forms an oval body near the core of the intrusion, and also occurs as isolated lenses and pods within the intrusion. The central body, previously interpreted to be a roof pendant or inclusion of volcanic country rock (Lovell 1972), consists of biotite hornblendite and diorite. Coarse euhedral cumulate hornblende grains are supported by intercumulus biotite, pyroxene and plagioclase. A regular decrease in grain size of the hornblendite approaching contacts with its syenite host is interpreted to be a chilling effect caused by the intrusion of the more mafic material into the syenite. The presence of syenite inclusions and diorite autoliths within

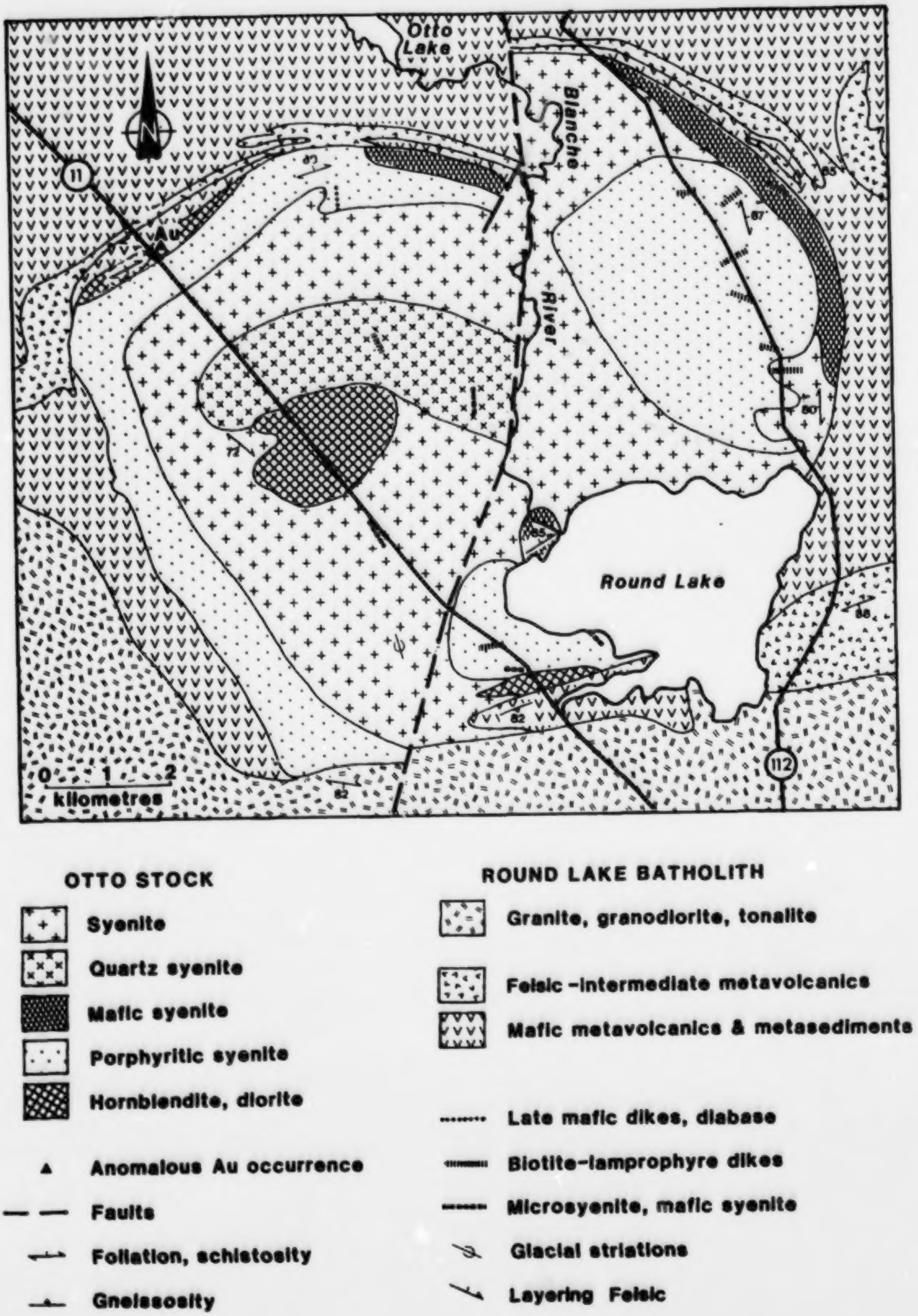

Otto Lake
Blanche River
Round Lake
11
112
Au
N
65
67
80
72
85
88
82
82
0 1 2
kilometres
OTTO STOCK
Syenite
Quartz syenite
Mafic syenite
Porphyritic syenite
Hornblendite, diorite
Anomalous Au occurrence
Faults
Foliation, schistosity
Gneissosity
ROUND LAKE BATHOLITH
Granite, granodiorite, tonalite
Felsic-intermediate metavolcanics
Mafic metavolcanics & metasediments
Late mafic dikes, diabase
Biotite-lamprophyre dikes
Microsyenite, mafic syenite
Glacial striations
Layering Felsic

Figure 28.3. *Generalized geology of the Otto Stock.*

hornblendite is additional evidence of the late intrusive nature of the ultramafic–mafic phase.

A sequence exposed on the northern shore of Round Lake consists of biotite hornblendite and heterogeneous melanocratic diorite interlayered with mafic syenite, leucocratic monzonite, and quartz syenite. The presence of hornblendite in this layered sequence is consistent with a magmatic origin for the ultramafic to mafic phase.

ECONOMIC GEOLOGY

Several different types of sulphide mineralization were observed in the Otto Stock during the current mapping. These include: 1) disseminated pyrite and pyrrhotite in hematitized syenite; 2) interstitial pyrite and chalcopyrite in coarse–grained, skeletal amphibole–bearing mafic syenite; 3) pyrite and molybdenite aggregates in quartz veins hosted in deformation zones; 4) chalcopyrite–bornite–pyrite–bearing fractures in aplite dikes; and 5) fine–grained, disseminated pyrite and pyrrhotite within lamprophyre dikes.

An anomalous gold value was obtained from a sulphide mineral occurrence of type 4. A grab sample from an aplite dike containing chalcopyrite in fractures returned values of 5800 ppm Cu and 165 ppb Au. The other mineral occurrence types listed above have been sampled, but assay results are not yet available.

These sulphide mineral occurrences may represent exploration targets for gold mineralization. In addition, interstitial chalcopyrite was outlined locally in the intrusive hornblendite core, and may represent an exploration target for PGE mineralization.

GHOST RANGE SILL

INTRODUCTION

The Ghost Range Sill is a layered ultramafic–mafic Archean body located south of the Abitibi Batholith, 45 km north of Kirkland Lake and 45 km east of Matheson at the intersection of Lamplugh, Frecheville, Holloway and Harker townships. The intrusion lies immediately north of Highway 101 and may be accessed via a network of logging roads extending to the north.

GEOLOGY

Previous geological mapping on the Ghost Range Sill was completed, at a variety of scales, between 1952 and the present (Satterly 1952, 1954; MacRae 1969; Jensen 1982c, d). As a result of this mapping, different interpretations have arisen as to the form and petrogenesis of the body. Satterly (1952b, 1954) concluded that the body is a layered sill, folded into a doubly–plunging syncline. MacRae (1969) identified a 760 m thick cumulate sequence of peridotite, pyroxenite and gabbro. Jensen and Langford (1985) suggested that the rocks probably represent the basal sequences of the Stoughton–Roquemaure Group and comprise thick, flat–lying lava flows resting unconformably on older, folded, volcanic rocks.

For this project, the Ghost Range Sill was mapped at a scale of 1:15 840 to examine its stratigraphy, to determine if the cumulus stratigraphy can be related to a complementary volcanic succession, and to assess the potential for economic PGE mineralization.

The Ghost Range Sill forms an elongate ridge, measuring 10 km east–west by 2 km north–south, and consists of coarse–grained mafic to ultramafic rocks. Topographically lower ground surrounding the ridge is underlain by calc–alkalic, felsic metavolcanic rocks of the Hunter Mine Group. Contact relations are poorly constrained; however, steep dips occur in both the volcanic rocks and on unit contacts and layers in the sill. Steep inward dips occur on both the northern and southern edges of the body, which is interpreted in this study to be a lopolith, with a gently north–dipping, flat top.

The units outlined during this mapping project, in stratigraphic order from base to top, include lherzolite (+ dunite), clinopyroxenite, gabbronorite (+ gabbro) and hornblende gabbro. The lherzolite at the base is medium–grained, composed predominantly of serpentinized olivine, and is characterized by oikocrystic pyroxenes and asbestos veinlets. Where pyroxene is locally absent, the rock is compositionally a dunite. This medium–grained clinopyroxenite unit is not laterally continuous, and was found only in zones of short strike length. It is <10 m in width and has a sharp contact with gabbronorite stratigraphically above.

The upper, mafic section of the sill has been subdivided into gabbronorite and hornblende gabbro. The gabbronorite unit is medium– to coarse–grained and is characterized by the presence of blocky orthopyroxene grains of variable grain size and abundance. Wispy layering, defined by variable orientations of orthopyroxene, clinopyroxene and plagioclase, is locally present. The hornblende gabbro is medium grained and is characterized by the presence of irregular quartz and magnetite–bearing pegmatitic gabbro patches. Uralitization and epidotization are more intense in the hornblende gabbro than in the underlying gabbronorite. Skeletal amphibole crystals are present within some pegmatitic patches.

ECONOMIC GEOLOGY

Previous exploration activity on the Ghost Range Sill outlined numerous asbestos occurrences within the ultramafic, basal portion of the intrusion.

Sulphide mineral occurrences are rare within the sill, and were detected at only two localities during the current mapping. Mineralization consists of disseminated pyrite in medium-grained hornblende gabbro. Samples from a section across the stratigraphic thickness of the intrusion are currently being assayed for platinum group elements.

CONCLUDING REMARKS

The geological mapping upon which this report is based serves to better define the geology of the intrusive bodies examined. It has discovered mafic plutonic rocks closely associated with both the Abitibi Batholith and the Otto Stock. In the Abitibi Batholith, gabbronorite and gabbro intrusions exhibit textures indicative of near contemporaneous emplacement with the host tonalite. In addition, a continuum of lithologies, from hornblende gabbro to diorite and quartz diorite, in bodies fringing the batholith suggests a substantial degree of differentation has occurred during this magmatism.

Ultramafic to mafic rocks were also discovered in alkalic felsic to intermediate rocks of the Otto Stock. Coarse hornblendite in the core of the stock, containing autoliths of diorite and syenite, was observed to have chilled contacts with the host syenite. This evidence, along with the presence of hornblendite within a layered mafic sequence, is consistent with a magmatic origin for this ultramafic rock.

Magmatic sulphide mineralization was identified in mafic/ultramafic rocks associated with the Abitibi Batholith, the Otto Stock, and, in addition, with the Ghost Range Sill. This presents a new exploration target for platinum group elements.

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29. Project Number 87-15. Geology of Tisdale and Northern Whitney Townships

D.W. Piroshco and K. Kettles

Geologists, Precambrian Geology Section, Ontario Geological Survey, Toronto.

INTRODUCTION

This report summarizes the results of the second and final year of mapping of Whitney and Tisdale townships. The two townships are located in the district of Cochrane (Figure 29.1), between Latitudes 48°27'N and 48°32'N and Longitudes 81°04'30"W and 81°20'W. The city of Timmins is located on the west-central boundary of Tisdale Township.

The purpose of the project is to update the geological data base of Tisdale and Whitney townships, to provide a framework for future mineral exploration, and to outline areas for further geological studies. The two townships contain the majority of past and producing mines in the Porcupine Mining Camp, and thus the main emphasis of the project is on defining the relationships between lithologies, structural elements, metamorphism/alteration, and gold mineralization.

Previous studies on the Porcupine Camp, providing the geological framework for this project, are too numerous to mention in this report. Most are summarized in the latest reports on the Timmins area by Pyke (1982), Fyon and Crocket (1983), Hodgson (1983a), and Mason and Melnik (1986).

Prospecting, exploration, and mining for gold have been continuous in the Timmins area in various degrees of intensity since the early 1900s. The most comprehensive overviews of the mining history in Tisdale and Whitney townships are provided by Ferguson *et al.* (1968) and Hodgson (1983b).

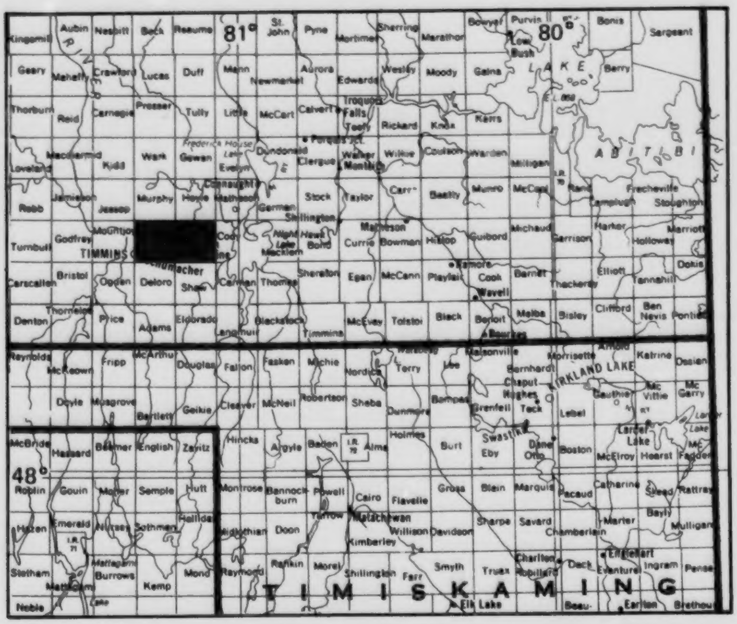
Kingsmill
Aubin
Nesbitt
Beck
Reaume
81°
St. John
Pyne
Mortimer
Sherring
Marathon
Bowyer
Purvis
Low Bush
80°
Bonis
Sargeant
Geary
Mahaffy
Crawford
Lucas
Duff
Mann
Newmarket
Aurora
Edwards
Wesley
Moody
Gains
LAKE
Berry
Thorburn
Reid
Carnegie
Prosser
Tully
Little
McCart
Calvert
Iroquois Falls
Teefy
Rickard
Knox
Kerrs
Frederick House Lake
Dundonald
Fergus Jct.
Walker
Monteith
Wilkie
Coulson
Warden
Milligan
ABITIBI
Loveland
Macdiarmid
Kidd
Wark
Gowan
Evelyn
Clergue
Connaught
Robb
Jamieson
Jessop
Murphy
Hoyle
Matheson
German
Stock
Taylor
Carr
Beatty
Munro
McCool
Rand
Frecheville
Lamplugh
Stoughton
Shillington
Turnbull
Godfrey
Mountjoy
TIMMINS
Night Hawk Lake
Bond
Mackiem
Matheson
Currie
Bowman
Hislop
Guibord
Michaud
Garrison
Harker
Holloway
Marriott
Schumacher
Carscallen
Bristol
Ogden
Deloro
Shaw
Carman
Thomas
Sheraton
Egan
McCann
Playfair
Ramore
Cook
Wavell
Barnet
Thackeray
Elliott
Tannahill
Dokis
Denton
Thorneloe
Price
Adams
Eldorado
Langmuir
Blackstock
Timmins
McEvay
Tolstoi
Black
Benoit
Bourkes
Melba
Bisley
Clifford
Ben Nevis
Pontiac
Reynolds
McKeown
Fripp
McArthur
Douglas
Fallon
Fasken
Michie
Nordica
Terry
Lee
Maisonville
Morrisette
Arnold
Katrine
Ossian
Bernhardt
KIRKLAND LAKE
Doyle
Musgrove
Bartlett
Geikie
Cleaver
McNeil
Robertson
Sheba
Dunmore
Bompas
Chaput Hughes
Grenfell
Teck
Lebel
Gauthier
Mc Vittie
Mc Garry
Larder Lake
McBride
Hassard
Beemer
English
Zavitz
Hincks
Argyle
Baden
I.R. 72
Alma
Holmes
Burt
Swastika
Eby
Dane
Otto
Boston
McElroy
Hearst
McFadden
48°
Roblin
Gouin
Moher
Semple
Hutt
Montrose
Bannockburn
Powell
Cairo
Flavelle
Gross
Blain
Marquis
Pacaud
Catharine
Skead
Rattray
Hazen
Emerald
Nursey
Sothman
Halliday
Midlothian
Doon
Yarrow
Matachewan
Willison
Davidson
Sharpe
Savard
Chamberlain
Marter
Bayly
Mulligan
Kimberley
I.R. 71
Stetham
Mattagami
Burrows
Mond
Raymond
Rankin
Morel
Shillington
Farr
Smyth
Truax
Charlton
Robillard
Dack
Englehart
Evanturel
Ingram
Pense
Mattagami
Kemp
TIMISKAMING
Elk Lake
Noble
Beau-
Earlton
Brethour

Figure 29.1. *Location map for the Tisdale and Whitney townships area, District of Cochrane. Scale: 1:1 584 000 or 1 inch to 25 miles.*

This project A.7.1. is part of the five year Canada-Ontario 1985 Mineral Development Agreement (COMDA), a subsidiary agreement to the Economic and Regional Development Agreement (ERDA) signed by the governments of Canada and Ontario.

REGIONAL GEOLOGY

Mapping by Burrows (1915, 1924), Hurst (1939), Dunbar (1948), Ferguson (1959a, 1959b), Carlson (1967), Leahy (1971), Roberts (1981) and Pyke (1970, 1972, 1975, 1978a, 1978b, and 1982) is the basis for the current geological interpretations of the Timmins area. The most recent regional map of the Timmins area is provided by Pyke (1982). Stratigraphic interpretations and correlations of the metavolcanics and metasediments have been provided by Burrows (1924), Hurst (1936), Dunbar (1948), Pyke (1982), and Hodgson (1983a). The relationship of the metavolcanic and metasedimentary rocks, based on Dunbar's (1948), Pyke's (1982), and Hodgson's (1983a) stratigraphic interpretations, is shown in Table 29.1 and Figure 29.1 of Piroshco and Kettles (1987).

DETAILED GEOLOGY

This section summarizes the major revisions, reinterpretations, and additions to the geology of the map area made during this project which have a bearing on the understanding of known gold mineralization. Most of the additions are refinements of the structural geology. These results are correlated with local mine interpretations presented by Bell (1948), Hawley and Hart (1948), Holmes (1948), and Price and Bray (1948).

PORCUPINE SYNCLINE AND NORTH TISDALE ANTICLINE (D_0)

The North Tisdale Anticline, outlined in northern Tisdale Township (Ferguson *et al.* 1968), can be traced southeastward through Whitney Township and is truncated by the Timiskaming Unconformity in east-central Whitney Township (Figure 29.2).

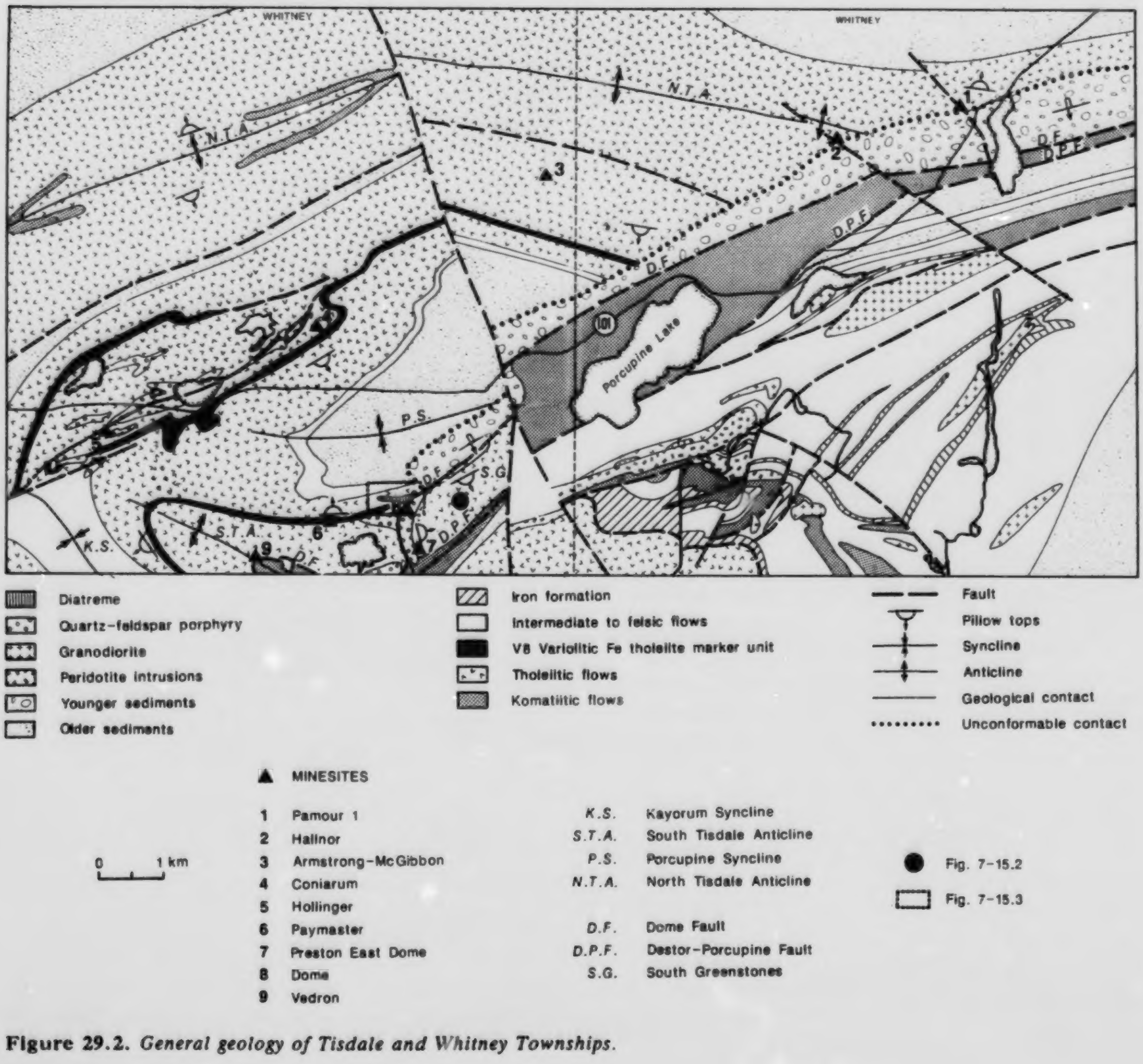
WHITNEY
WHITNEY
N.T.A.
N.T.A.
3
1
2
D.F.
D.P.F.
D.P.F.
D.F.
101
Porcupine Lake
P.S.
D.F.
S.G.
S.T.A.
6
K.S.
9
D.F.
8
7
D.P.F.
Diatreme
Quartz-feldspar porphyry
Granodiorite
Peridotite intrusions
Younger sediments
Older sediments
Iron formation
Intermediate to felsic flows
V8 Variolitic Fe tholeiite marker unit
Tholeiitic flows
Komatiitic flows
Fault
Pillow tops
Syncline
Anticline
Geological contact
Unconformable contact
MINESITES
1 Pamour 1
2 Hallnor
3 Armstrong-McGibbon
4 Coniarum
5 Hollinger
6 Paymaster
7 Preston East Dome
8 Dome
9 Vedron
0 1 km
K.S. Kayorum Syncline
S.T.A. South Tisdale Anticline
P.S. Porcupine Syncline
N.T.A. North Tisdale Anticline
D.F. Dome Fault
D.P.F. Destor-Porcupine Fault
S.G. South Greenstones
Fig. 7-15.2
Fig. 7-15.3

Figure 29.2. *General geology of Tisdale and Whitney Townships.*

The axial surface of the fold is interpreted to intersect the unconformity near the Hallnor minesite, based on the presence of opposing pillow facings northeast and southwest of this location (Figure 29.2). Similarly, the axial surface of the Porcupine Syncline (Ferguson *et al.* 1968) can be extrapolated to intersect the unconformity in eastern Tiscale Township. The truncation of the axial surfaces of these folds along the unconformity indicates that they pre-date the deposition of the Younger Sediments and therefore represent the earliest recognizable structures in the map area, designated D_0 in this study.

YOUNGER SEDIMENTS—DOME FAULT—PORPHYRY INTRUSIONS (D_1)

Following deposition, the Younger Sediments were truncated and rotated into a subvertical, south-facing attitude along the southeast-dipping Dome Fault (Hodgson 1983a). At the same time, movement along the Dome Fault juxtaposed the Younger Sediments against the Tisdale Group volcanic rocks to the south (the South Greenstones, *see* Figure 29.2). The Dome Fault is best defined in southeastern Tisdale Township in the vicinity of the Preston East Dome minesite (Figure 29.2), where it swings north–south and is referred to as the "footwall fault" (Hawley and Hart 1948). At this location, the South Greenstones face eastward, as opposed to the northwest-facing rocks of the Greenstone Nose (Ferguson *et al.* 1968).

Direct evidence for the kinematics of the Dome Fault was not obtained in this study, but the apparent older-on-top-of-younger relationship demonstrated by the Younger Sediments and South Greenstones suggests the fault is a thrust or reverse fault. There is indirect supportive evidence for this interpretation at a roadcut outcrop in the South Greenstones (Figure 29.2), where turbidites are intercalated with southwest-facing mafic flows. Detailed examination of the lithological contacts at this outcrop reveals that, in at least one instance, a clear discordancy exists between bedding and the lithological contacts (Figure 29.3). The contacts are therefore interpreted as faults. Within the westernmost turbidite unit (Figure 29.3), north-inclined, open- to chevron-style folds plunging shallowly (10° to 30°) northeast are present (Photo 29.1), with a steeply north-dipping, axial planar foliation (S_1). These folds are interpreted as drag folds developed as a result of reverse faulting.

Porphyry intrusions were emplaced both into brittle, east-trending fractures and along the Dome Fault during this deformation episode. This interpretation would imply that the porphyry intrusions are younger than, or the same age as, the Younger Sediments, but crosscutting relationships were not observed to confirm or disprove this.

SOUTH TISDALE ANTICLINE—KAYORUM SYNCLINE (D_2)

These folds, which plunge northwestward and are overturned to the southwest (Ferguson *et al.* 1968), are accompanied by an axial planar foliation which trends 100° to 130° and dips steeply to moderately northeastward (S_2). This foliation is locally developed throughout Tisdale Township and is dominant

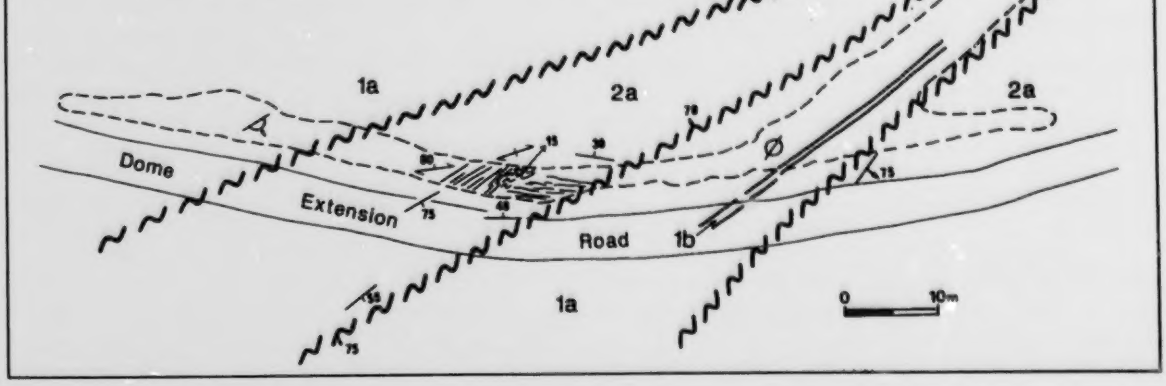
outcrop
pillows; tops known, unknown
bedding; tops known, unknown
foliation; inclined, vertical
trend and plunge of folds
fault
1 tholeiitic mafic volcanic rocks
a pillowed
b breccia
2 metasedimentary rocks
a slate and siltstone
N
1a
2a
2a
Dome
Extension
Road
1b
1a
15
30
70
90
75
45
75
55
75
0
10m

Figure 29.3. *Geology of the Dome Extension road outcrop (South Greenstones).*

Photo 29.1. *Outcrop (Dome Extension road) showing near upright, chevron-style folds in turbidites.*

in southern Tisdale Township, but is rarely recognized in Whitney Township. It cuts the Tisdale Group rocks, Older Sediments, Younger Sediments, and porphyries. In addition, the folds and foliation deform and crosscut the Dome Fault, outlined by the apparent folding of the porphyry intrusions at the Vedron Property. This deformation is also associated with locally developed sets of gold-mineralized, extensional quartz veins that trend 100° to 130° and dip 25° to 60° southwest. These veins are particularly well developed at the Armstrong–McGibbon Property in northeastern Tisdale Township (Map 2075 of Ferguson *et al.* 1968), where they occur as an *en echelon* set within a massive, east-trending mafic flow.

EAST-NORTHEAST-TRENDING FABRIC (D_{3a})

Superimposed on the northwest-trending foliation in southern Tisdale Township is a locally well developed planar fabric (S_{3a}), trending 070° to 090° and dipping steeply north to south (Photo 29.2). This fabric is recognized throughout the map area and is dominant in the northern half of Tisdale and Whitney townships. In southern Tisdale Township, the intersection of this fabric with the northwest-trending foliation plunges 40° to 60° northeastward to eastward, parallel with the trend and plunge of stretched varioles and conglomerate clasts in this area. In eastern Whitney Township away from the influence of the northwest-oriented structures, stretching lineations are absent and the east-northeast planar fabric is recognized as a bedding-parallel flattening of conglomerate clasts in the Dome Formation.

Well developed sets of gold-mineralized, extensional quartz veins trending 020° to 050° and dipping 40° southeastward (Photo 29.3) are also associated with this flattening fabric. This vein style is dominant in the ore zones developed in polymictic conglomerate and turbidite units at the Pamour 1 Mine (Price and Bray 1948). Another set of gold mineralized veins, that trend parallel with the earlier northwest-trending foliation (S_2), is dominant at the Vedron Prospect in southern Tisdale Township and is also interpreted to have formed during this deformation.

Moderately northeast-plunging, 'S'-shaped folds (up to 30 m in scale), which are best developed within the turbidites of the Dome Formation, are spatially related to the planar fabric and vein sets. The folds are exposed in both Tisdale and Whitney townships and are shown in underground geological plans of the Hallnor and Pamour 1 mines. They typically display a well developed, northwest-dipping, axial planar foliation and limb shears, showing a left-handed rotation of earlier cleavage.

The orientation of planar fabrics, folds, and vein elements, described above and termed D_{3a} in this study, provides consistent kinematic evidence for left-handed reverse movement along northeast-trending faults described in the Hallnor Mine by Bell (1948) and in the Pamour 1 Mine by Price and Bray

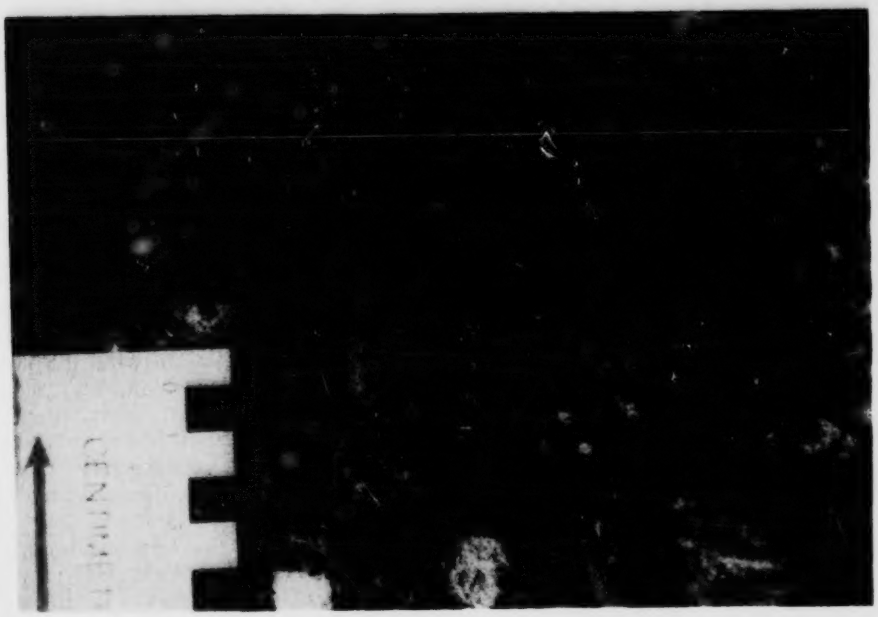

Photo 29.2. *Outcrop, located at the Vedron Property, illustrating the crosscutting relationship between the northwest (120°—S_1) and east-northeast-(80°—S_2)-trending foliations in carbonatized tholeiitic volcanic rocks of the Tisdale Group.*

Photo 29.3. *Photograph of the south wall of the No. 3 Pit at the Pamour 1 Mine, showing well developed, shallowly southeast-dipping extensional quartz veins crosscutting turbidites of the Dome Formation.*

(1948). These faults host the steeply to moderately dipping, mineralized vein systems of these mines.

NORTHEAST-TRENDING FABRIC (D_{3a})

A fourth planar fabric recognized in the map area is a 030° to 060°-trending crenulation cleavage (S_{3a}) which cuts the northwest-trending cleavage in the turbidites of the Dome Formation and the east-northeast-trending fabric in the tholeiitic rocks at the Hollinger Mine. In the turbidites exposed near the Dome Mine, right-handed, bedding-parallel slip (060°-trending) is observed, as demonstrated by a 'Z'-shape-folded quartz vein, and offset of the vein. The orientation and kinematics of these slip surfaces and the orientation of the foliation (030°) are consistent with their formation in a single deformation episode, termed D_{3a} in this study.

LATE STRUCTURES

Northwest-trending, right-handed faults and northeast-trending, left-handed faults with mapped offsets of up to 40 m postdate the penetrative foliations. These brittle faults are typically characterized by subhorizontal slickensides and narrow (1 to 5 cm wide) zones of fault gouge. North-trending, vertically dipping, gash-like extension veins, which are barren of gold, are locally developed in the map area and are interpreted to be related to this late deformation. The latest structural feature are north- to northwest-trending diabase dykes, which commonly are closely spatially related to ore bodies in the mines.

FRAGMENTAL ROCKS AT THE DOME MINE—SEDIMENTARY TROUGH(?)

The Sedimentary Trough is a 300 to 400 m long, west-tapering wedge or tongue of fragmental rock and slate/siltstone that cuts across the Tisdale Group rocks (Ferguson *et al.* 1968 and Figure 29.4) and has yielded approximately 50 percent of the gold recovered from the Dome Mine (Holmes 1948). The structure extends vertically to the 3900-foot level of the Dome Mine (Chart D, E, and F *in* Ferguson *et al.* 1968) and shows a consistent, intimate spatial relationship with the Paymaster Porphyry on its eastern margin. It is approximately 150 m wide at its thickest part to the east, where it swings northeastward, around a structure referred to as the "Greenstone Nose" (Holmes 1948). Ferguson *et al.* (1968) described the rocks within the structure as Younger Sediments and interpreted it as a deep valley or fracture in the Tisdale Group rocks. The interpretation of the rocks as sediments was based on the apparent intercalation of slate/siltstone units with the fragmental rock and the correlation of the fragmental rock with the conglomerates of the Younger Sediments.

Detailed (1:100) mapping was carried out in a restricted area (400 m by 800 m) at the Dome minesite in order to examine the Sedimentary Trough in detail (Figure 29.4). The fragmental rock

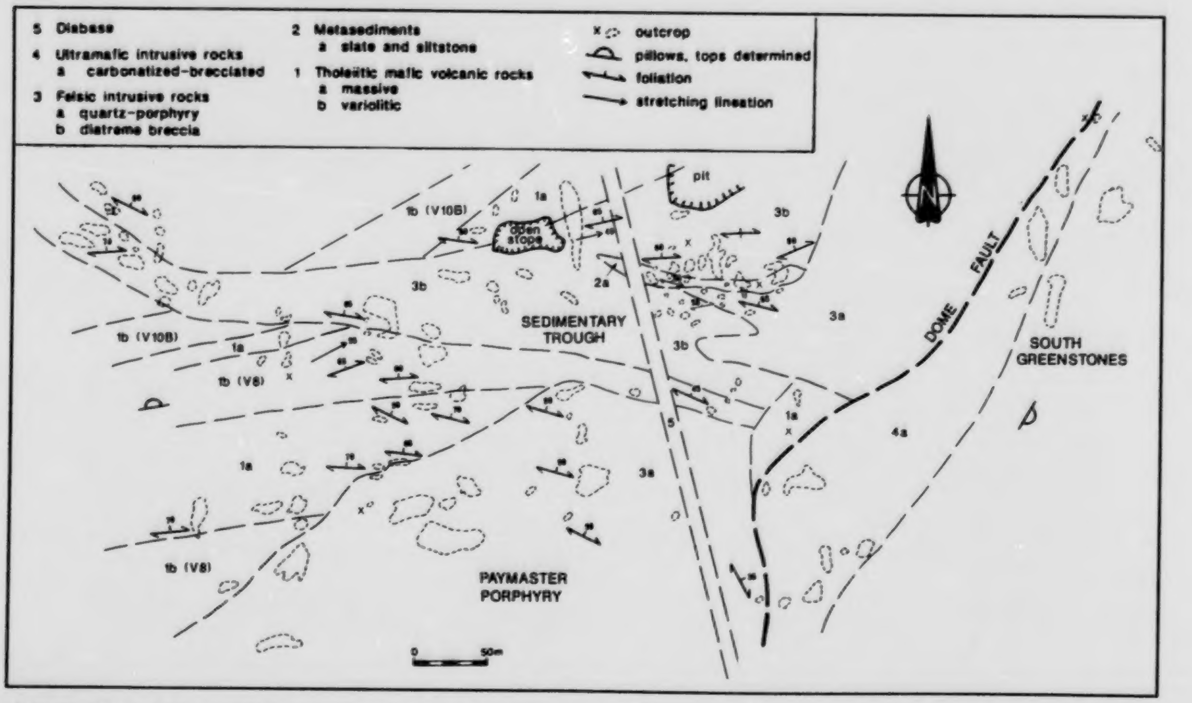
5 Diabase
4 Ultramafic intrusive rocks
a carbonatized-brecciated
3 Felsic intrusive rocks
a quartz-porphyry
b diatreme breccia
2 Metasediments
a slate and siltstone
1 Tholeiitic mafic volcanic rocks
a massive
b variolitic
outcrop
pillows, tops determined
foliation
stretching lineation
pit
1a
1b (V10B)
open stope
3b
2a
SEDIMENTARY TROUGH
1b (V10B)
1a
1b (V8)
3a
3b
5
1a
4a
DOME FAULT
SOUTH GREENSTONES
1b (V8)
PAYMASTER PORPHYRY
0
50m

Figure 29.4. *Geology of the eastern portion of the Dome Mine (Sedimentary Trough area). The legend is modified after Ferguson et al. (1968).*

Photo 29.4. *Outcrop, located at the Dome/Paymaster minesites boundary, showing the contact between tholeiitic volcanic rocks of the Tisdale Group and the fragmental rocks of the Sedimentary Trough.*

was found to consist of variable proportions of angular to subrounded clasts of mafic volcanic rock and quartz porphyry in amounts ranging from 20 percent to 70 percent. The clasts are up to 50 cm by 20 cm in size, are unsorted and are locally rimmed by fine-grained, dark-grey chlorite and quartz. The matrix consists of fine-grained chlorite, quartz, and calcite. A slate/siltstone unit in sharp contact with the Paymaster Porphyry (Figure 29.4) was found to be discordant (northwest trend) with the northeast trend of the Younger Sediments and the east-northeast trend of the Tisdale Group volcanic rocks.

The contact between the trough and the mafic volcanics of the Tisdale Group is exposed at the Dome-Paymaster minesites boundary. The contact is highly irregular and gradational, marked by *in situ* fragmentation of the mafic volcanic wall rock and dikelets of breccia in the wall rock (Photo 29.4).

In this study, the Sedimentary Trough is interpreted as a diatreme or breccia pipe genetically related to the intrusion of the Paymaster Porphyry. This interpretation is based on the recognition that the porphyry fragments are identical in texture and lithology to the Paymaster Porphyry and therefore are probably derived from it. The fragmental rocks within the Trough, therefore, cannot be sedimentary in origin because the Paymaster Porphyry is located stratigraphically up-section from the Trough (the South Greenstones and Younger Sediments face south, *see* Figure 29.2). In addition, the breccia shows a marked textural and lithological similarity with breccia dykes described at the Coniaurum Mine (Piroshco 1983; Piroshco and Hodgson, in press). The slate unit mapped within the Trough is interpreted in this study as a structural enclave of Older Sediments, based on its discordancy with lithological trends.

SUMMARY AND CONCLUSIONS

At least two stages of gold-mineralized quartz veins, which developed in two distinct, relatively late, deformation events, are recognized in this study. The earlier veins are extensional structures that dip shallowly southwest and are interpreted to have formed synchronously with northwest-trending structures (D_2) such as the South Tisdale Anticline. The later veins are the most dominant and formed synchronously with a later deformation event characterized by east-northeast-trending structures (D_{3a}). Most veins related to this deformation occupy east-northeast-trending faults and fractures but, in one instance (Vedron Prospect), the veins are parallel to the earlier northwest-trending foliation (S_2).

A strong east- to northeast-plunging stretching lineation observed in the southern half of Tisdale Township is coincident with the intersection lineation produced by the superposition of the east-northeast structures (D_{3a}) on the northwest structures (D_2). In eastern Whitney Township where northwest-oriented structures are poorly developed, this stretching lineation is absent.

At the Dome Mine, a unit previously interpreted as Younger Sediment (the Sedimentary Trough) is reinterpreted as a diatreme breccia genetically related to the intrusion of the Paymaster Porphyry. This lithology is host to approximately 50 percent of the ore mined at the Dome Mine and therefore represents a new, preferred host lithology for gold mineralization around porphyry intrusions in the Porcupine Camp.

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30. Project Number 88–33. The Abitibi Greenstone Belt Near Larder Lake: Structural and Stratigraphic Studies

S.L. Jackson

Geologist, Precambrian Geology Section, Ontario Geological Survey, Toronto.

INTRODUCTION

The Late Archean Abitibi Greenstone Belt in the Kirkland Lake Area has been subdivided (Jensen 1978; Jensen and Langford 1985) into distinct komatiitic, tholeiitic, and calc–alkaline volcanic–dominated groups, some containing significant amounts of sedimentary lithologies, and the Timiskaming Group of sedimentary and alkaline volcanic rocks. These groups were thought to represent a stratigraphic continuum extending from the eastern margin of the Round Lake Batholith to the centre of the Blake River Syncline (*see* Figure 5 of Jensen and Langford 1985). Recurrence of similar lithologic groups within the proposed stratigraphic column was attributed to cyclic volcanism. Recent geochronological data (Corfu *et al.*, in press; Marmont and Corfu 1988) are somewhat inconsistent with such a stratigraphic model. Furthermore, recent structural investigations (Toogood and Hodgson 1985, 1986; Hamilton 1986; Hodgson and Hamilton, in preparation; Hodgson *et al.*, in preparation) within the Kirkland Lake–Larder Lake Area have resulted in the recognition of distinct lithostructural domains. Most of these are bounded by shear zones, which obscure stratigraphic relationships.

Geologic mapping, aimed at elucidating both the inter– and intra–domainal structure and stratigraphy, was initiated in 1988 in the vicinity of McVittie Township (*see* Figure 30.1 and Figure 30.2). This field work, reported herein, marks the start of a systematic mapping project to be continued in subsequent years.

REGIONAL GEOLOGY

Four major lithostructural domains have been identified (Hodgson *et al.*, in preparation) in the vicinity of Larder Lake (Figure 30.2). These, using Hodgson *et al.*'s numbering scheme, include the following.

Domain 2 (approximately equivalent to the Larder Lake Group; *see* Jensen and Langford 1985) is an assemblage of ultramafic and mafic volcanic rocks and sedimentary rocks, consisting predominantly of conglomerate and sandstone. In several locations, the volcanic rocks and sedimentary rocks have "back–to–back" facing relationships (e.g.

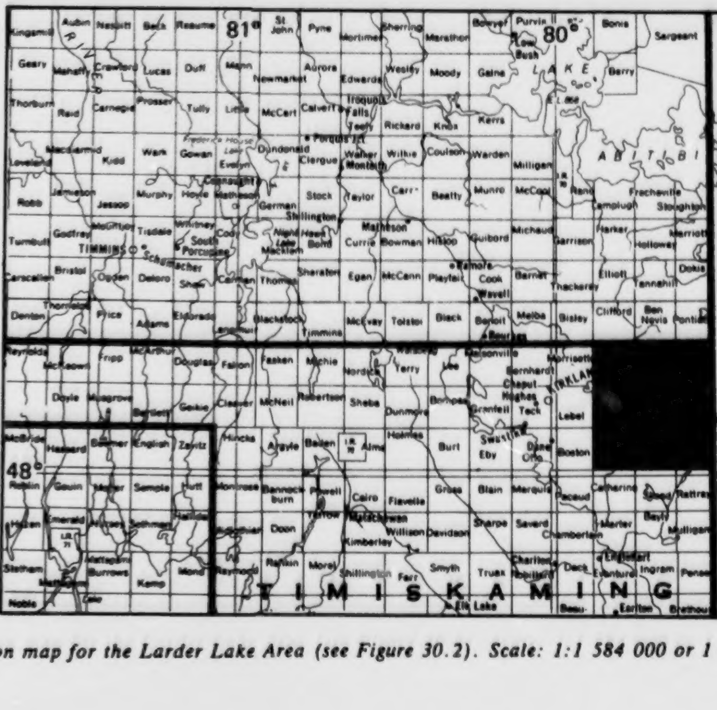


Figure 30.1. *Location map for the Larder Lake Area (see Figure 30.2). Scale: 1:1 584 000 or 1 inch to 25 miles.*

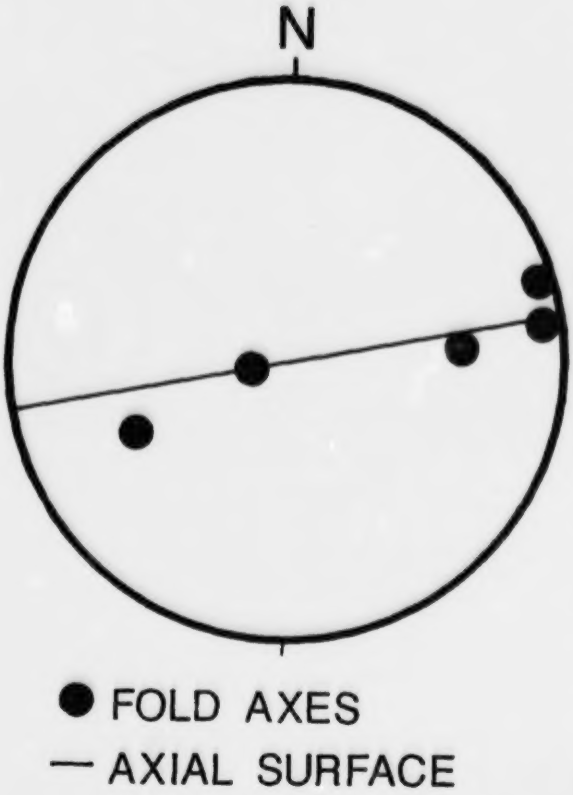


Figure 30.2. *Lithostructural domains (modified after Hodgson et al., in preparation) in the Larder Lake Area. Numbered domains, except Domain 1 (see Hodgson et al., in preparation), are discussed in text. Open diamonds represent calc–alkaline volcanic rocks; open triangles represent mafic volcanic rocks; dots represent sandstones and conglomerates; filled triangles represent ultramafic and mafic volcanic rocks; thin lines represent feldspar porphyry and syenite; thick lines represent gabbroic rocks; thick curvilinear lines represent faults; dashed line labelled M represents the Monocle Lake Deformation Zone; P stands for Proterozoic rocks; L stands for Larder Lake; and F stands for the fault referred to in the text. See text for further information.*

Thomson 1949, Hearst Township Map, 0.5 km east of Sharp Creek). It is unclear if the "back–to–back" relationships are due to a major unconformity or tectonic juxtaposition of distinct lithological assemblages, or both. Corfu *et al.* (in press) and Marmont and Corfu (1988) obtained an age of 2705 Ma from a tuff that is intercalated with ultramafic flows. Structurally, this zone is characterized by map–scale fold interference patterns (e.g. Thomson 1949, Hearst Township Map).

Domain 4, the Kirkland Lake–Larder Lake Deformation Zone (KLDZ) (Hamilton 1986), separates Domains 2 and 7. It is underlain predominantly by the Timiskaming Group sedimentary and alkaline volcanic rocks, and lesser amounts of feldspar and quartz–feldspar porphyritic intrusions, carbonate+quartz±fuchsite schists, talc–chlorite schists, and mafic to ultramafic rocks. The KLDZ is approximately east–striking, 1 to 3 km wide, and, in Ontario, over 60 km long. Steeply dipping planar fabrics (principally schistosities, cleavages, fractures, shear planes, and foliations defined by flattened and/or elongated clasts and fragments) are of variable, but generally east–west, orientation. Clast and fragment elongation directions and fold axes are generally steeply plunging. However, shallowly plunging folds are also present.

This domain is clearly the most important from an economic perspective, since most major gold mines (past and present producers) in the area are located within it. Many workers have drawn attention to the association of gold, deformation zones, carbonate alteration, and felsic intrusions within this domain (e.g. Hamilton 1986; Hodgson *et al.*, in preparation, and references therein).

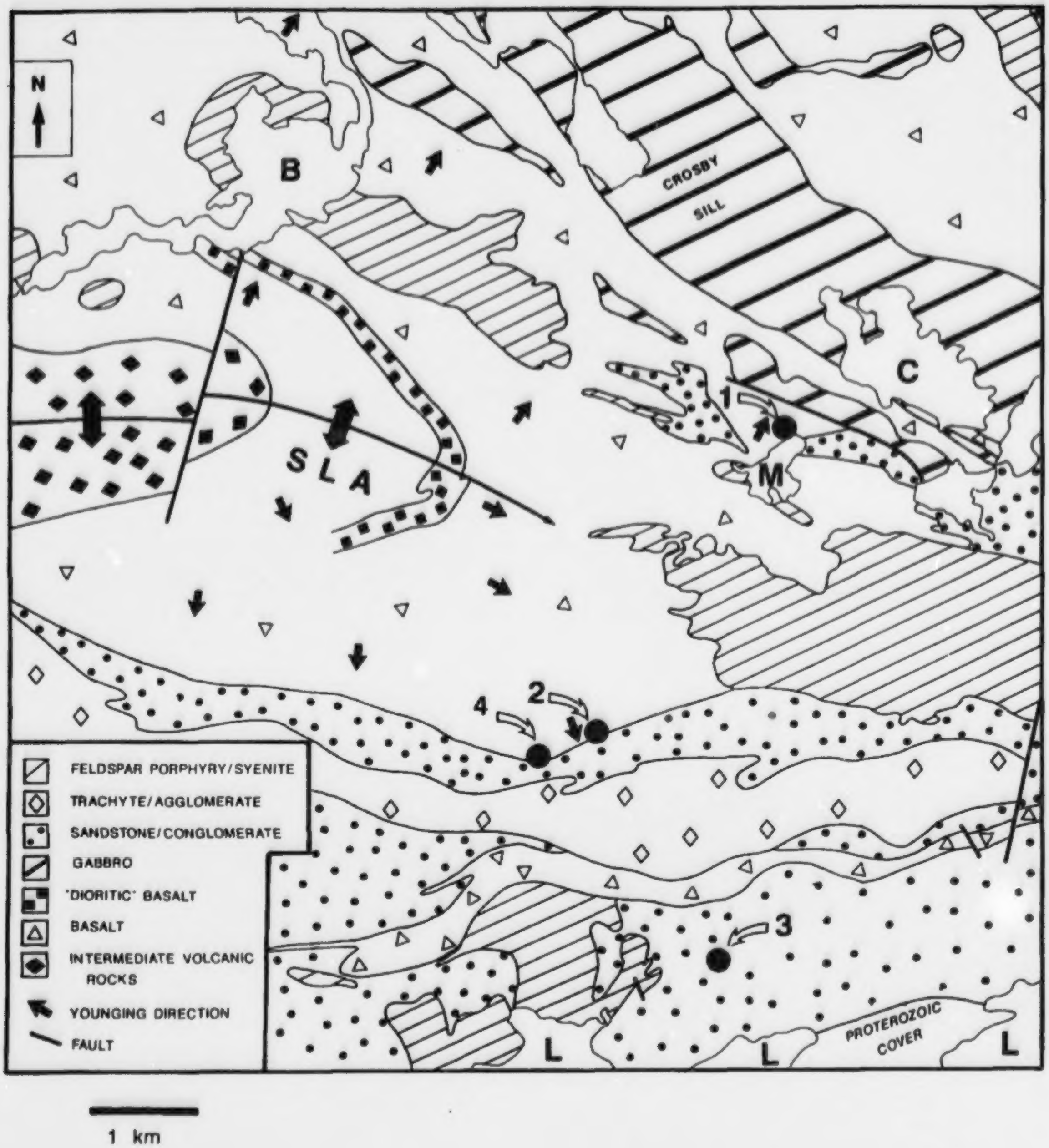
Domain 7 includes both the tholeiitic basalt suite of the Kinojevis Group and the calc–alkaline, fragmental suite of the Gauthier Group. These groups, and the younging directions obtained from them, define the east–southeast–plunging Spectacle Lakes Anticline (Thomson 1949). Penetrative fabrics are only locally developed in this domain.

Domain 8 is composed of the 2701 Ma (Marmont and Corfu 1988) calc–alkaline suite of volcanic rocks belonging to the Blake River Group. Penetrative fabrics are generally absent from this zone. However, near major faults (e.g. Fault "F", Figure 30.2), steeply dipping cataclastic foliations, flattened pillows, and weak penetrative foliations are observed.

SUMMARY OF RESULTS

Some of the principal results of the 1988 field work are:

1. In southernmost Domain 4 (KLDZ) are folds with variable plunges, but constant axial surface orientations that parallel the KLDZ. The formation of these folds is correlated with the formation of the KLDZ.
2. Based on orientation and apparent relative timing, at least three sets of shear zones are recognized within the KLDZ (Domain 4).
3. Depositional contacts between basaltic rocks of the Kinojevis Group (Domain 7) and sedimentary rocks of the younger Timiskaming Group are exposed on both the northern and southern limbs of the Spectacle Lakes Anticline. At other localities, the Kinojevis–Timiskaming contact is highly strained.
4. A zone, approximately 1 km wide, of anomalously high strain is present south of the Crosby Sill (Figure 30.3) along the northern side of the Spectacle Lakes Anticline. This zone is herein


N
B
CROSBY SILL
C
1
M
SLA
2
4
3
L
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L
PROTEROZOIC COVER
FELDSPAR PORPHYRY/SYENITE
TRACHYTE/AGGLOMERATE
SANDSTONE/CONGLOMERATE
GABBRO
'DIORITIC' BASALT
BASALT
INTERMEDIATE VOLCANIC ROCKS
YOUNGING DIRECTION
FAULT
1 km

Figure 30.3. *Geology of McVittie Township (modified after Thomson 1943). SLA stands for Spectacle Lakes Anticline. Numbered dots refer to locations discussed in the text. B, C, L, and M stand for Beaverhouse, Crosby, Larder, and Monocle lakes, respectively.*

referred to as the Monocle Lake Deformation Zone (Figure 30.2). Interpretation of fabric geometry within the zone indicates a predominantly sinistral sense of displacement.

MESOSCOPIC FOLDS IN THE SOUTHERN PART OF THE KIRKLAND LAKE–LARDER LAKE DEFORMATION ZONE

Where observed to date (e.g. location 3, Figure 30.3), these open to isoclinal folds vary from sub-

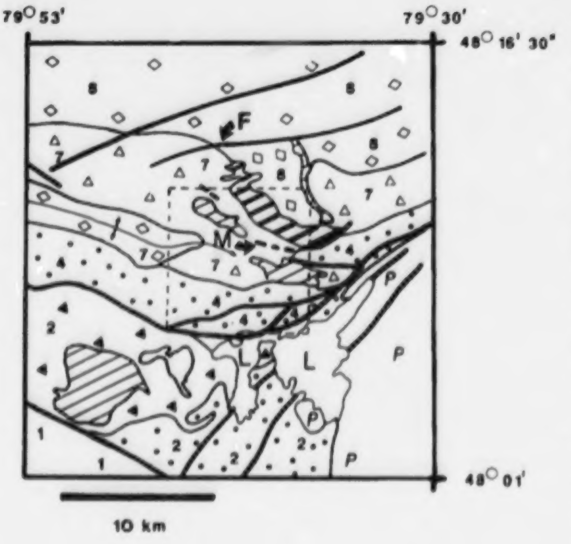

Figure 30.4. *Equal area plot of fold axes and the approximate axial planes of folds from location 3 of Figure 30.3.*

horizontal to steeply plunging within a few metres, but have consistent, steeply dipping, east–trending axial surface orientations (Figure 30.4). Axial surfaces, axial planar schistosity, and sheared limbs of the folds all parallel the trend of the KLDZ. This parallelism suggests that the folds and the KLDZ are related. No fabric oblique to the trend of the fold axes was observed. Therefore, the variation in plunge direction of the folds is attributed to a single phase of deformation involving the progressive rotation of early–formed, uniformly plunging fold axes. There is considerable potential for gaining insight into the kinematics of the KLDZ by unravelling the deformation history of the sediments in and immediately south of it.

KIRKLAND LAKE–LARDER LAKE DEFORMATION ZONE (KLDZ)

Three different shear zones (or sets thereof) are recognized on the basis of orientation. The inferred relative timing of these, from oldest to youngest, is: 1) east–southeast–trending shear zones; 2) north–trending shear zones; and 3) east–northeast to east–trending shear zones. Fabrics and structures from the KLDZ have been described in detail by Hamilton (1986). At present, it remains unclear whether the different shear zones represent discrete events (e.g. Hodgson *et al.*, in preparation), or different stages of development of one continuous event. Further work is required to resolve both this problem and the problem of developing a kinematic model for fabric development with the KLDZ (*see* for example Toogood and Hodgson 1985, p.201).

KINOJEVIS GROUP–TIMISKAMING GROUP CONTACTS

Depositional contacts (locations 1 and 2, Figure 30.3; Photo 30.1) between, and relative positions of, the Kinojevis tholeiitic basalts and Timiskaming sedimentary rocks exposed on the southern and north-

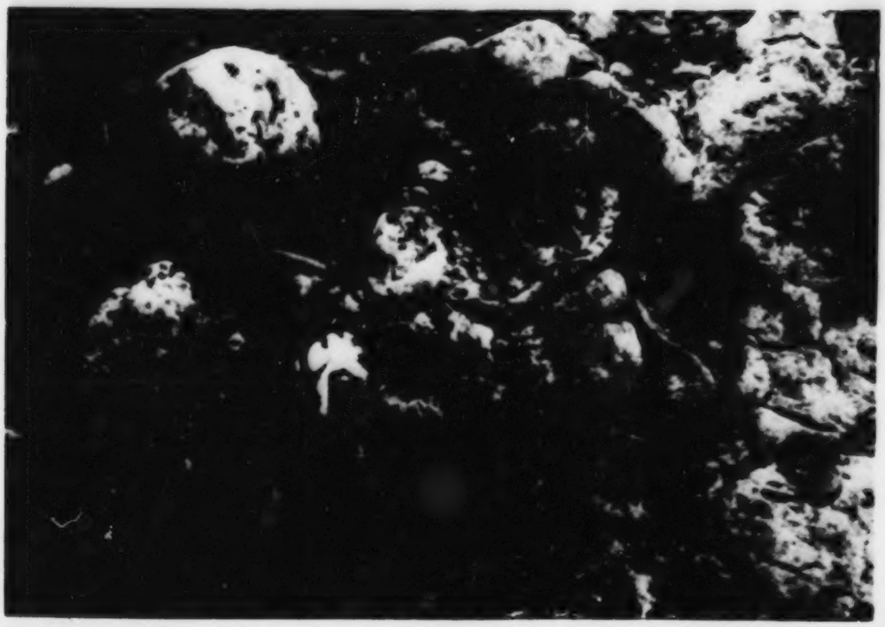

Photo 30.1. *Timiskaming Group conglomerate (top left) in contact with Kinojevis Group basalts (bottom right). Photo from location 2 of Figure 30.3.*

ern limbs of the Spectacle Lakes Anticline, are consistent with an anticlinal structure cored by the older Kinojevis Group. The southern contact dips moderately to the south. There, large boulders and cobbles of basalt at the very base of the Timiskaming are similar to the underlying basalt. There is no evidence of displacement, high strain, or faulting at the contact. In addition, narrow fractures in the basalt unit are filled with conglomerate. The contact on the northern limb of the anticline is more strained, but displays features similar to those found at the southern contact. At other localities (e.g. location 4, Figure 30.3), high strain has concealed the original nature of the contact. Furthermore, rocks near the high strain zones have experienced weak to intense carbonate alteration (location 4, Figure 30.3; *see also* McVittie Township Map of Thomson 1943).

It is clear that the Timiskaming was deposited, at least in part, on top of the Kinojevis Group basalts, and that subsequent deformation modified the original nature of the contact. It is unclear, however, to what extent the angular discordance between the two groups (e.g. McVittie Township Map, Thomson 1943) is due to deformation and/or an angular unconformity (*see* Thomson 1946; Toogood and Hodgson 1986; Hamilton 1986).

MONOCLE LAKE DEFORMATION ZONE

The Monocle Lake Deformation Zone (*see* Figure 30.2 for location) is a zone of high strain that separates massive gabbroic rocks of the Crosby Sill from massive basalts of the Kinojevis Group. The full extent of the zone and its tectonic significance are, as yet, unknown. Some rocks within the zone exhibit slight to moderate degrees of carbonate alteration. This zone is also associated with feldspar±quartz porphyry intrusions and some gold mineralization (e.g. the Ker–Vit Mine).

Fabrics and structures found within the zone include: spaced (mm to cm scale) fractures in pillowed basalt, folded pillow selvages with penetrative axial planar schistosity, highly flattened conglomerate clasts, pressure solution cleavage in sandstone layers, and well–developed schistosities in both metasediments and metabasaltic rocks. These fabrics are, generally, east– to southeast–trending and steeply to moderately north–dipping. However, a limited zone, just northwest of Monocle Lake, of shallowly dipping to subhorizontal schistosity is present.

The flattened clasts, schistosities, and pressure solution cleavages within this deformation zone are west–northwest–trending and are deflected by a "later", east–trending, moderately to steeply north–dipping spaced crenulation to fracture cleavage. This "later" fabric deflects the earlier fabrics to yield a geometry consistent with a sinistral displacement sense (Photo 30.2). It is possible that the "later" fabric developed synchronously with the compressive fabrics, and would therefore represent "c" fabrics of a sinistral shear system.

One kilometre east of Monocle Lake, in a Timiskaming sandstone–conglomerate sequence, the "later" (or "c") fabrics are subparallel to lithological contacts. This sugguests that layer–parallel displacement (of unknown magnitude) occurred during de-

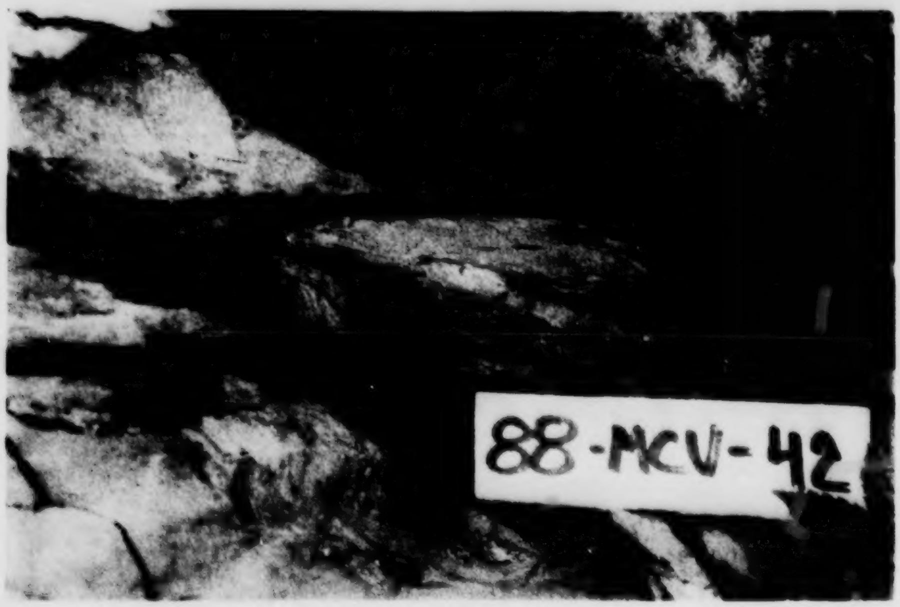

Photo 30.2. *Highly flattened and sheared Timiskaming conglomerate. Note that flattened clasts are deflected into a "Z" asymmetry, indicating a sinistral displacement sense. Photo taken 1 km east of the northern end of Monocle Lake.*

formation, and that at least some lithologic contacts in the deformation zone are tectonic contacts.

Northwest of Monocle Lake, on northern Beaverhouse Lake within McVittie Township, basalts of the Kinojevis Group display flattened pillows, local penetrative schistosity, and spaced fractures, all of which are steeply dipping and west-northwest-trending. The deformation in this area may be related to the deformation near Monocle Lake.

A 30° to 40° north-dipping seismic reflector (G. West, Geophysicist, University of Toronto, personal communication, 1988) projects to the surface approximately where the Monocle Lake Deformation Zone crops out. Furthermore, where studied to date, this zone separates rocks of the Kinojevis Group from the Crosby Sill and the Blake River Group to the north. Other deformation zones, such as the northwest-trending carbonated shear zone in Morrissette Township (Rupert and Lovell 1970), occur along strike from the Monocle Lake Deformation Zone. The shear zone in Morrissette Township is, like the Monocle Lake Deformation Zone, associated with Timiskaming Group sedimentary rocks, carbonate alteration, and gold mineralization, and occurs near the boundary of the Kinojevis Group and Blake River Group. The available evidence indicates that the Monocle Lake Deformation Zone is an important regional structure that controls the distribution of major lithologic assemblages.

CLOSING REMARKS

This preliminary study has provided new observations regarding the structures within, and the nature of the contacts between, some of the lithostructural domains in the Kirkland Lake–Larder Lake area. Systematic mapping and related studies will be carried out within this area in subsequent years. In addition to producing updated maps, this work should clarify our understanding of: 1) the internal structure, stratigraphy, and absolute ages of the lithostructural domains; 2) the structural–stratigraphic relationship between domains; and 3) the relationship between the metamorphic event(s), deformation, alteration, mineralization, and magmatism.

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31. Project Number 87–01. Relationships Between Lithological, Alteration, and Structural Features and Precious–Metal Occurrences in the Temagami Greenstone Belt, District of Nipissing

J.A. Fyon[1], R.B. Hrabi[1], and W.M. Maitland[2]

[1]Geologists, Precambrian Geology Section, Ontario Geological Survey, Toronto.

[2]Graduate Student, Department of Geology, University of New Brunswick, Box 4400, Fredericton, New Brunswick, E3B 5A3.

INTRODUCTION

The intent of this project is to document the spatial, temporal, and genetic relationships among various lithologies, alteration types, and styles of deformation, and distribution and types of precious–metal occurrences in the Temagami Greenstone Belt. Aspects of this project contribute to the broader problem of Archean gold metallogeny, specifically the structural and plutonic phenomena responsible for the localization of gold within, and the development of an apparent gold–base metal zonation along, a zone of deformation. In addition, the causal relationships between regionally extensive zones of deformation and coincident stratigraphic discontinuities, recognized in the Temagami Greenstone Belt, are relevant to litho–stratigraphic syntheses in other greenstone belts.

In this, the second year of the Temagami Minerals Project, detailed mapping (1:8000) focused on Archean rocks in parts of Briggs and Chambers townships. Some gold properties in Strathy Township were examined at a scale of 1:100. The townships are bounded approximately by the following Longitudes and Latitudes: 79°45′28″W to 79°53′00″W and 47°3′30″N to 47°8′30″N (Strathy Township); 79°53′00″W to 80°0′30″W and 47°3′30″N to 47°8′30″N (Chambers Township); 79°53′00″W to 80°0′30″W and 46°58′00″N to 47°3′30″N (Briggs Township). Chambers Township is accessed via Highway 11 and adjacent logging roads, notably the Red Squirrel Road system. Briggs Township is accessed through the Lake Temagami Access Road, located 6 km south of the town of Temagami, and the Northeast Arm of Lake Temagami (Figure 31.1).

Two relationships, relevant to stratigraphic and gold metallogenic problems, were addressed this summer. Virtually all gold occurrences occur within a restricted segment of one broad zone of deformation (Net Lake–Vermilion Lake Zone of Deformation) which separates two packages of metavolcanic rock. The localization of gold mineralization, with attendant alteration, is directly attributed to the structural evolution along that segment of the zone of deformation. This zone of deformation forms a "ramp–like" structure along which much of one metavolcanic package appears to have been truncated and removed (Figure 31.2a and 31.2b). This may imply that the two adjacent metavolcanic packages are structurally juxtaposed and, hence, their temporal and genetic relationships remain obscure.

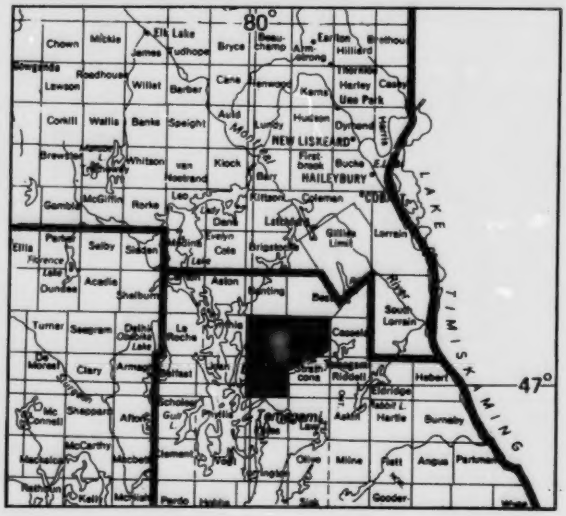
80°
Chown
Mickle
Elk Lake
James
Tudhope
Bryce
Beau-champ
Arm-strong
Earlton
Hilliard
Lawson
Roadhouse
Willet
Barber
Cane
Kerns
Harley
Casey
Uno Park
Corkill
Wallis
Banks
Speight
Auld
Lundy
Hudson
Dymond
Harris
NEW LISKEARD
Brewster
Whitson
van Nostrand
Klock
Firstbrook
Bucke
HAILEYBURY
Gamble
McGiffin
Rorke
Leo
Kittson
Coleman
Lady Dean
Latchford
Gillies Limit
Lorrain
Ellis
Selby
Sladen
Evelyn
Cole
Brigstocke
Florence Lake
Dundee
Acadia
Shelburne
Aston
Banting
South Lorrain
Turner
Seagram
Delhi
Obabika Lake
La Roche
Casey
De Morest
Clary
Armagh
Belfast
Strathcona
Riddell
Hebert
47°
Eldridge
Mc Connell
Sheppard
Afton
Scholes
Gull L.
Phyllis
Temagami
Askin
Hartle
Burnaby
McCarthy
Macbeth
Olive
Milne
Angus
Rathbun
Kelly
Pardo
Gooderham
LAKE TIMISKAMING

Figure 31.1. *Location map for the Temagami Minerals Project. Scale: 1:1 584 000 or 1 inch to 25 miles.*

This project A.4.2 is part of the five year Canada–Ontario 1985 Mineral Development Agreement (COMDA), a subsidiary agreement to the Economic and Regional Development Agreement (ERDA) signed by the governments of Canada and Ontario.

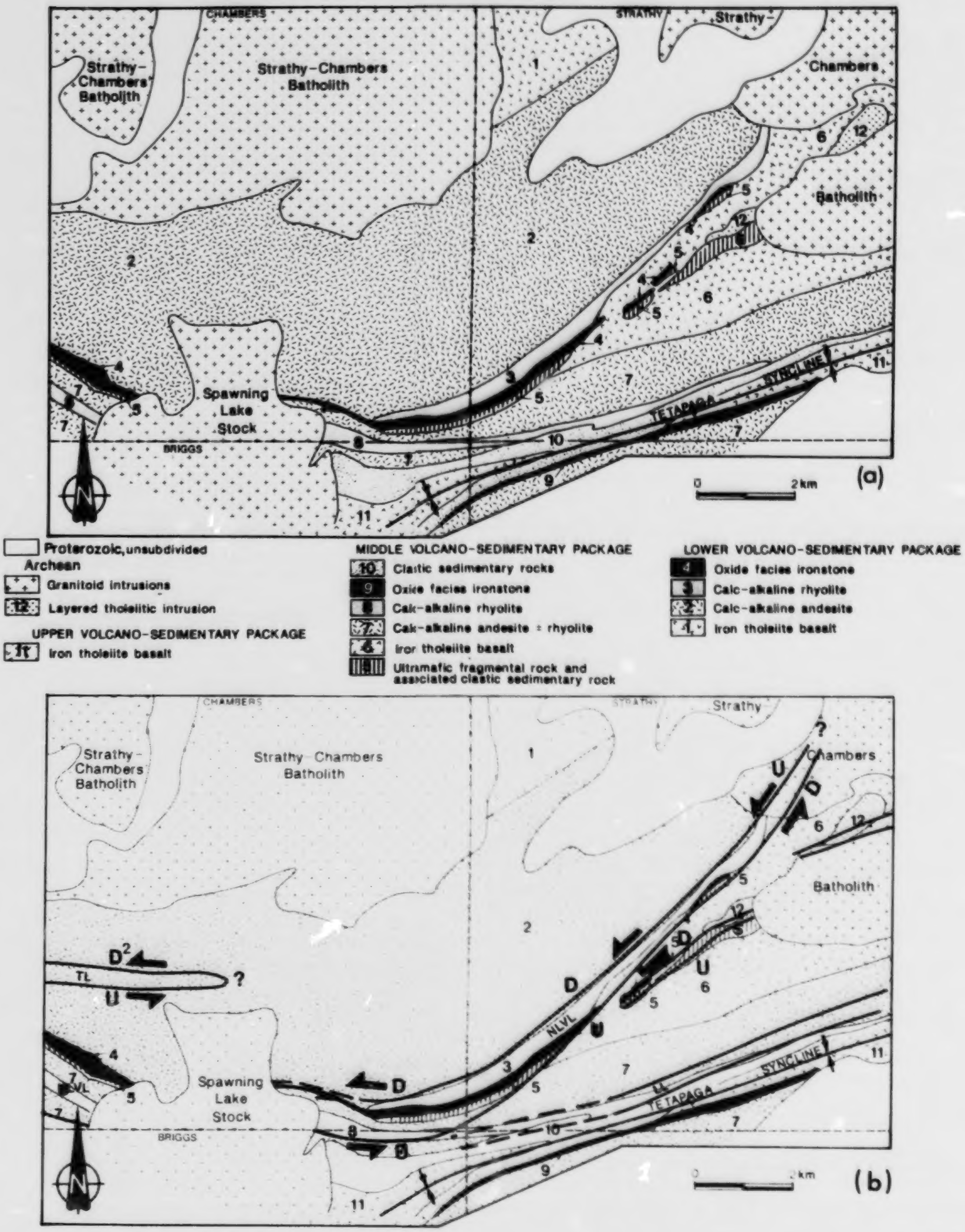
CHAMBERS
STRATHY
Strathy-Chambers Batholith
Strathy-Chambers Batholith
Strathy
Chambers
Batholith
Spawning Lake Stock
BRIGGS
SYNCLINE
TETAPAGA
1
2
3
4
5
6
7
8
9
10
11
12
0
2km
(a)
Proterozoic, unsubdivided
Archean
Granitoid intrusions
12 Layered tholeiitic intrusion
UPPER VOLCANO-SEDIMENTARY PACKAGE
11 Iron tholeiite basalt
MIDDLE VOLCANO-SEDIMENTARY PACKAGE
10 Clastic sedimentary rocks
9 Oxide facies ironstone
8 Calc-alkaline rhyolite
7 Calc-alkaline andesite ± rhyolite
6 Iron tholeiite basalt
5 Ultramafic fragmental rock and associated clastic sedimentary rock
LOWER VOLCANO-SEDIMENTARY PACKAGE
4 Oxide facies ironstone
3 Calc-alkaline rhyolite
2 Calc-alkaline andesite
1 Iron tholeiite basalt
TL
D²
U
?
NLVL
LL
D
U
(b)

Figure 31.2. *(a) Distribution of Archean volcano-sedimentary packages, late Archean intrusions and Proterozoic rock in Strathy, Chambers, and part of Briggs townships. The distribution and composition of lithological divisions is highly simplified. (b) Distribution of major zones of deformation in the Temagami Greenstone Belt. Abbreviations are as follows: TL Tasse Lake; NLVL Net Lake-Vermilion Lake; LL Link Lake; U-side with upward vertical component of motion; D-side with downward component of motion. Arrows indicate the relative sense of horizontal motion along Tasse Lake and Net Lake-Vermilion Lake Zones of Deformation, although both experienced an oblique, sinistral component of motion. The NLVL Zone of Deformation appears to form as "ramp-like" structure which separates the Lower and Middle Volcano-sedimentary Packages.*

These two characteristics of the Temagami Greenstone Belt are extremely important because of their implications for Archean stratigraphic analysis and gold exploration. The characterization of rock alteration, within and outside the zones of deformation, remains an integral aspect of this study, but details are not discussed at this stage, except for some large-scale observations on the distribution of secondary carbonate.

GENERAL GEOLOGY

Field observations complement those of Savage (1936), Moorehouse (1946), and Bennett (1978). Fyon and Crocket (1986) and Fyon and O'Donnell (1987) suggested a three-fold subdivision of the volcano-sedimentary rocks (Figure 31.2). This preliminary subdivision into coherent rock packages has been retained as a result of this year's work, but Group and Formation assignment is no longer used, given the uncertain chronological and genetic relationships between successive rock packages. The subdivision is elaborated to emphasize key features relevant to important stratigraphic and metallogenic problems. It is emphasized that this is perceived as a geometrical, and not necessarily as a chronological, subdivision.

LOWER VOLCANO-SEDIMENTARY PACKAGE (LVP)

The LVP consists of a basal, iron-rich, tholeiitic basalt unit; a central division of calc-alkaline, effusive and fragmental rocks; and an upper division of chemical and clastic sedimentary rocks. The basal, tholeiitic basalt unit is not well represented because much of its stratigraphic position is occupied by a tonalite-trondhjemite intrusion (Strathy-Chambers Batholith; Figure 31.2a). Aphyric and mega-feldspar-phyric, pillowed flows are typical, but variolitic flows have not been recognized.

The calc-alkaline rocks consist of massive, pillowed, and pyroclastic flows and related debris deposits. Andesite (feldspar-hornblende(?)-phyric) debris-type deposits are the dominant rock type in this division, although dacite and rhyolite (feldspar-quartz-hornblende(?)-phyric) effusive flows and fragmental deposits predominate at the top of the succession.

Banded units of chert-magnetite-hematite-ferruginous silicate ironstone and chert-pyrite ironstone lie at the top of the LVP. The oxide facies unit extends for at least 15 km across Chambers and Strathy townships, and is the source of iron ore at the Sherman Iron Mine (West and North Pits).

MIDDLE VOLCANO-SEDIMENTARY PACKAGE (MVP)

The lowest division of the MVP consists of fragmental, ultramafic rock and heterolithic clastic sediments. Overlying this basal division is an iron-rich, tholeiitic basalt unit, followed by a sequence of calc-alkaline effusive flows and fragmental rocks. Clastic and chemical sediments lie at the top of the MVP.

The ultramafic fragmental rock is in contact with, but stratigraphically above, the unit of chert-magnetite-hematite-ferruginous silicate ironstone which defines the top of the LVP (Fyon and O'Donnell 1987). In northwest Strathy Township, pyroxene-rich phases of possible extrusive origin are intimately associated with the ultramafic fragmental rock (Good 1987). Cursory chemical characterization of the ultramafic fragmental rock shows that it has some komatiitic characteristics. Spatially associated with the ultramafic fragmental rock is a unit of coarse, heterolithic, matrix-supported conglomerate. This poorly exposed clastic unit consists of mafic volcanic and intrusive fragments and rare chert and magnetite-chert clasts.

Overlying the ultramafic fragmental division is a sequence of iron-rich, tholeiitic basalt flows. Massive, pillowed, variolitic and mega-feldspar-phyric effusive flows are typical. This division was named the Arsenic Lake Formation by Fyon and Crocket (1986).

Toward the top of the MVP, effusive and pyroclastic flows and related debris deposits of calc-alkaline affinity predominate. Debris-type deposits appear to be less abundant than in the LVP. Conversely, effusive andesite and pyroclastic rhyolite flows appear to be more abundant in the MVP, relative to the LVP. This division was named the Link Lake Formation by Fyon and Crocket (1986).

An assemblage of chemical and clastic sedimentary rock lies at the top of the MVP. The sedimentary division consists of thin-bedded, sandstone-mudstone couplets of turbiditic origin and a wedge-shaped unit of coarse, heterolithic, resedimented conglomerate. Banded-chert-magnetite-hematite-ferruginous silicate ironstone occurs toward the top of the clastic division, and defines the top of the MVP (South and East Pit iron deposits, Sherman Mine). No ultramafic fragmental unit has been recognized within this sedimentary sequence. This clastic and chemical sedimentary division was termed the Turtle Lake Formation (Fyon and Crocket 1986).

UPPER VOLCANO-SEDIMENTARY PACKAGE (UVP)

The UVP consists only of iron-rich, tholeiitic basalt flows, which are preserved in the core of a regional syncline (Tetapaga Syncline; Figure 31.2a). Neither variolitic nor mega-feldspar-phyric flows have been identified.

LATE INTRUSIONS

A more comprehensive discussion of intrusive rocks in the area is provided by Bennett (1978) and Fyon and O'Donnell (1987). Only some characteristics of the post-volcanic intrusions, relevant to the structural chronology, are presented.

TONALITE-TRONDHJEMITE

The Strathy-Chambers Batholith, located in northern Chambers and Strathy townships, appears to be a single phase tonalite-trondhjemite intrusion, which contains minor amounts of pegmatite and aplite. An amphibolite facies contact metamorphic aureole surrounds the intrusion and the trend of the metavolcanic stratigraphy parallels the margin of the intrusion. A flattening fabric (S_0/S_1), attributed to the earliest regional deformation, is developed in the outer margin of the intrusion (*see* below).

TRONDHJEMITE-GRANODIORITE

The Iceland Lake Stock, located in Briggs and Strathcona townships, is a composite trondhjemite-granodiorite pluton, consisting of chlorite trondhjemite, hornblende quartz diorite and hornblende trondhjemite phases (Bennett 1978). The trend of metavolcanic units in Briggs and Strathcona townships is parallel to the intrusion contact. A flattening fabric (S_0/S_1), attributed to the earliest deformation of the greenstone belt, is present in the outer margin of the intrusion (*see* below).

MICROCLINE MEGACRYSTIC GRANITE

The Spawning Lake Stock carries up to 50 percent microcline megacrysts, 2 to 3 cm in diameter. This intrusion truncates a regional fold axis (Tetapaga Syncline) and a zone of deformation (western extension of the Net Lake-Vermilion Lake Zone of Deformation), but bears none of the related deformation fabrics. It is grossly discordant to lithological layering.

BIOTITE LAMPROPHYRE DIKES

Several dikes of this kindred were observed within zones of deformation. This meagre data base suggests that biotite lamprophyre dikes are preferentially localized within or adjacent to zones of deformation; however, there are exceptions where lamprophyre dikes occur outside zones of high strain. Lamprophyre dikes have two preferential strike orientations (000° and 300°; Bennett 1978, p.44), parallel to some deformation zones and Proterozoic diabase dikes. Biotite lamprophyre dikes cut the outer margins of the Iceland Lake and the Spawning Lake stocks.

STRUCTURAL FEATURES

Described below, chronologically and in terms of increasing scale, are the regional deformation characteristics of the greenstone belt. Two styles of folding and four zones of ductile deformation can be related to three discrete penetrative foliations.

EARLY FOLIATION (S_0/S_1)

The notation S_0/S_1 is used to designate this foliation, because the distinction between transposed primary layering (bedding?) and a tectonic foliation is not possible in some zones of high strain. This foliation is generally east-trending in Chambers and Strathy townships and has a steep dip. Its strike is parallel to bedding, major stratigraphic units, and the margins of the Strathy-Chambers and Iceland Lake intrusions. Changes in foliation strike are generally sympathetic with changes in bedding strike. The mineral and fragment dimensional elongation developed on this foliation plane is steeply plunging.

SHEAR FOLIATION (S_2)

A shear foliation (S_2) is developed in two shear zones: the Net Lake-Vermilion Lake (NLVL) and the Tasse Lake Zones of Deformation. It has a steep dip, with a steeply plunging mineral and fragment dimensional elongation. The consistent left-handed displacement of some quartz veins, lithological units and dikes, and the development of apparent S-C fabric relationships along the NLVL Zone of Deformation are evidence consistent with a sinistral component of motion. No shallowly plunging mineral or fragment dimensional elongation was observed.

LATE FOLIATION (S_3)

This is a north-trending foliation which is recognized in all metavolcanic and metasedimentary rocks and in the Strathy-Chambers Batholith. It has a steep dip, but mineral lineations were rarely observed. This foliation is axial planar to open folds having a wavelength and amplitude of 10 to 40 cm where observed on individual outcrops, and 10s to 100s m where inferred on a township scale. Both S_0/S_1 and S_2 appear to be folded by S_3, although examples of unequivocal overprint relationships between S_2 and S_3 are few.

TETAPAGA SYNCLINE

The Tetapaga Syncline is the largest recognizable regional fold (Bennett 1978). Its axial plane has an east trend across the southern part of Strathy and Chambers townships, parallel to S_0/S_1 and the stratigraphic attitudes of the metavolcanic and metasedimentary units. Rocks of the MVP are repeated on either side of the Tetapaga Syncline and the iron-rich tholeiitic basalts of the UVP occupy the core of the syncline in Strathy and Chambers townships. The thickness of the UVP within the synclinal core increases toward eastern Strathy Township and toward western Briggs Township, with the minimum thickness corresponding approximately with the Strathy-Briggs Township junction. This implies that the Tetapaga Syncline is doubly plunging on a regional scale.

The Spawning Lake Stock truncates the fold axial surface. East of the Spawning Lake Stock, minor folds have a shallow easterly plunge, while mineral lineations and clast elongation plunge steeply to the southeast. West of the Spawning Lake Stock, mineral lineations plunge westerly. This doubly plunging aspect of the fold, adjacent to the Spawning Lake Stock, may be related to doming associated with the intrusion emplacement. The Spawning Lake Stock appears to be unaffected by the strain associated with the development of the Tetapaga Syncline.

ZONES OF DEFORMATION

Four major zones of ductile shear are defined on the basis of intense foliation development: Link Lake, Northeast Arm, Net Lake–Vermilion Lake, and Tasse Lake Zones of Deformation (Bennett 1978; Fyon and O'Donnell 1987). Several narrower zones of high strain occur outside the major zones of deformation.

Link Lake and Northeast Arm Zones of Deformation

The Link Lake and Northeast Arm Zones of Deformation are characterized by a very strongly developed flattening foliation and a strong vertical dimensional elongation of fragments. Foliation has an easterly trend with a vertical to subvertical dip, approximately parallel to bedding attitudes, to the surface trace of the Tetapaga Syncline axial plane and to the regional S_0/S_1 foliation. Additional characteristics of these zones are described by Fyon and O'Donnell (1987). No gold showings having proven tonnage occur within either of these zones.

Net Lake–Vermilion Lake Zone of Deformation

In western Strathy Township, the S_2 shear foliation has a 030° trend, oblique to the regional bedding. In southern Chambers Township, the attitude of the shear foliation is west to northwest, approximately subparallel to bedding units. The zone of intense fabric development is approximately 1 km in width, and coincides with the contact zone between the LVP and MVP. Small–scale asymmetric kinematic indicators are consistent with a dominant, oblique, subvertical component of motion, with a lesser, sinistral, horizontal component. In western Strathy Township, regional bedding and the S_0/S_1 foliation (080°) are rotated into parallelism with the 030° shear foliation. The sense of this rotation, observed at a township scale, is also consistent with a component of sinistral horizontal translation.

Many of the gold occurrences that have proven grade and tonnage occur within the northeast segment in this zone of deformation, between Vermilion and Net lakes (Bennett 1978), although none occur within the western segment.

In southern Chambers–northern Briggs townships, the shear zone is localized along a unit of felsic metavolcanic rock (middle of MVP). Minor S–folds, kink structures, and crenulations are well developed and have steeply plunging fold axes, parallel to mineral and clast elongation. The developmental chronology of these minor structures remains equivocal, in part because this segment of the zone of deformation may reflect the superposition of the NLVL Zone of Deformation upon the pre–existing, westward extension of the Link Lake Zone of Deformation.

Tasse Lake Zone of Deformation

This zone of deformation extends from the western boundary of central Chambers Township, easterly through Tasse Lake, approximately parallel to volcanic layering. It is at least 0.5 km in width, and has been traced for about 3 km along strike. It is not certain if, or how far, this zone extends to the east of Tasse Lake, although it does not extend to the eastern boundary of Chambers Township.

Kinematic asymmetry is consistent with a dominant oblique, south–side–up sense of displacement, and a sinistral horizontal component. This kinematic sense is similar to parts of the NLVL Zone of Deformation, with which this zone of deformation may be related. No gold occurrences have been found in this zone.

STRUCTURAL CHRONOLOGY

In western Strathy Township, the early S_0/S_1 foliation (080°) is rotated adjacent to and is therefore older than the 030° shear fabric of the NLVL shear zone. The NLVL Zone of Deformation cuts and therefore post–dates the intrusion of the outer margin of the Strathy–Chambers Batholith. Feldspar–phyric dikes, possibly representing early expressions of Spawning Lake Stock magmatism, are deformed in the NLVL Zone of Deformation, although the main mass of the Spawning Lake Stock appears undeformed. When observed within the NLVL Zone of Deformation, biotite booklets within late lamprophyre dikes are aligned parallel to the shear foliation. These biotite lamprophyre dikes cut the outer margin of the Spawning Lake Stock. Thus, the lamprophyre dikes and Spawning Lake Stock may have been intruded late in the deformation history, but were emplaced into an existing stress field. Apparent differences in strain intensity between the dikes and the main mass of the Spawning Lake Stock may be related to differences in rheology.

STRUCTURAL INTERPRETATIONS

The identification of "events" to which the development of the foliations can be attributed must be done cautiously, given the scale of observation.

Early S_0/S_1 Foliation and Tetapaga Syncline

The S_0/S_1 foliation is interpreted to represent the earliest regional flattening of the volcano–sedimentary lithologies, and developed in response to north–

south shortening. The parallelism between S_0/S_1 and the axial planar foliation of the Tetapaga Syncline implies that the Tetapaga Syncline also formed contemporaneously with the early foliation.

Link Lake and Northeast Arm Zones of Deformation

The Link Lake and Northeast Arm Zones of Deformation are interpreted to represent paired high strain zones which are developed on either side of the Tetapaga Syncline. The deformation fabrics are symmetrical, suggesting an overall coaxial (irrotational) strain. The parallelism between the flattening foliation (S_0/S_1) within and outside the zones of deformation and the axial planar foliation to the Tetapaga Syncline is consistent with the contemporaneous development of the these two zones of deformation in response to north–south compression, contemporaneously with the development of the Tetapaga Syncline. This "event" may have resulted from progressive diapirism during the intrusion of the Strathy–Chambers and Iceland Lake intrusions.

S_2 and Tasse Lake and Net Lake–Vermilion Lake (NLVL) Zones of Deformation

Based on the consistent asymmetric kinematic relationships within these zones of deformation, regardless of the orientation of the zone, it is concluded that these are zones of simple shear, which formed in response to north–south directed stress. However, it is not possible to establish unequivocally if the Tasse Lake–NLVL and Link Lake Northeast Arm Zones of Deformation developed contemporaneously, in response to progressive deformation. As a tentative working hypothesis, the S_0/S_1 and S_2 foliations, and related zones of high strain, appear to have developed at different times.

S_3

The development of the north–trending foliation reflects east–west shortening. The doubly plunging nature of the Tetapaga Syncline may also be a larger scale manifestation of this shortening. However, understanding of the scale and significance of this event is still limited.

STRUCTURAL REPETITION ALONG THE NLVL ZONE OF DEFORMATION

The distribution of lithologies suggests the presence of three volcano–sedimentary sequences. The LVP and MVP are grossly similar in their internal succession and chemical affinity of rock types. These three volcano–sedimentary packages may represent a simple layer–cake stratigraphy, or may reflect the structural juxtaposition of lithologies. Three working hypotheses are consistent with the empirical field data: 1) the three volcano–sedimentary packages are stratigraphically independent, but represent a simple layer–cake stratigraphy constructed by successive volcanic eruptions; 2) the lithological packages represent a set of structurally stacked "slices" derived from one original, relatively simple volcano–sedimentary succession; and 3) the lithological packages represent a set of structurally stacked "slices" derived from "exotic" terrains.

Although it is not possible, at present, to discriminate unequivocally among the three working hypotheses, in part because precise geochronological data are lacking, some field evidence points to localized thrusting and structural repetition along the NLVL Zone of Deformation. The ultramafic fragmental and adjacent oxide–facies ironstone represent a "regional", distinctive lithological marker couple, which is exposed along a 15 km strike length (Figure 31.2a). However, in northwest Strathy Township, two units of ultramafic fragmental rock are exposed. A more pyroxene–rich (extrusive?) phase lies on the hanging wall of a thin oxide facies ironstone along the eastern shore of Net Lake. The second exposure, consisting of both olivine– and pyroxene–bearing extrusive phases, is located 600 m to the east along the eastern contact of a layered tholeiitic intrusion (locality described in more detail by Good 1987). The presence of oxide facies ironstone, 200 m along strike to the southwest from the tholeiitic intrusion–ultramafic fragmental unit contact, suggests that, even at this locality, the ironstone–ultramafic fragmental rock dyad is preserved. As discussed, this is the only locality along a 15 km strike length where the ultramafic fragmental unit is exposed at more than one stratigraphic horizon.

An east–dipping (50°) shear zone defines the contact between the ultramafic fragmental rock unit and the layered tholeiitic intrusion at the one locality where this contact is exposed (Canada Vein–INCO Limited). The kinematics of this shear are consistent with a reverse, east–side–up component (thrust) along this shear zone. Thus, structural repetition of the ultramafic fragmental rock is highly probable along at least one segment of the NLVL Zone of Deformation.

The observation that structural repetition of the ultramafic fragmental rock has taken place, at least locally, along the NLVL Zone of Deformation is not sufficient evidence to conclude that the entire NLVL Zone of Deformation has been the locus of structural juxtaposition of lithological packages. However, these empirical structural relationships significantly strengthen that hypothesis.

NLVL ZONE OF DEFORMATION AS A RAMP STRUCTURE

The geometrical relationship between metavolcanic lithologies within the LVP and MVP suggests that the NLVL Zone of Deformation represents a ramp–like structure, along which two volcano–sedimentary packages have been juxtaposed. In northwest

Strathy Township, a wedge of iron-rich tholeiitic basalt (lower part of the MVP) is in contact with the ironstone at the top of the LVP, whereas in south-central Chambers Township, rhyolitic rock (interpreted to lie toward the top of the MVP) is in contact with the ironstone marker (Figure 31.2b). Thus, it is apparent that the NLVL Zone of Deformation cuts across, and removes a significant part of, the volcanic "stratigraphy" from the MVP, where juxtaposed against the ironstone marker at the top of the LVP.

LOCALIZATION OF GOLD OCCURRENCES IN AN EXTENSIONAL BEND

Bennett (1978) pointed out a high frequency of gold occurrences along the northeast-trending segment of the NLVL Zone of Deformation. Given the continuity of this zone of deformation for a minimum of 15 km, the localization of such an abundance of gold occurrences along such a restricted part of the structure is problematical. However, given the kinematic analysis of this shear zone (sinistral horizontal component), the northeast-trending segment would have behaved as a dilational jog, and experienced a component of extension. The western segment of this zone of deformation would not have been subjected to such a component of extension. Thus, the localization of the large number of gold occurrences in this segment of the NLVL Zone of Deformation is a consequence, at least in part, of the tectonic evolution along this zone.

ROCK ALTERATION

The general distribution of secondary mineral assemblages in the Temagami Greenstone Belt has been addressed by Bennett (1978), Beswick and James (1984), Fyon and Crocket (1986), and Fyon and O'Donnell (1987). During the course of this two-year study, approximately 60 levels of subdivision for alteration categories were recognized. The distribution of some secondary minerals does not correspond with the surface trace of the zones of deformation (e.g. habits of albitization); alternatively, the distribution of other secondary minerals (e.g. ferroan carbonate) corresponds closely with zones of deformation.

It is significant to note that while ferroan carbonate is present in all zones of deformation, its introduction along the NLVL Zone of Deformation was most intense in the northeast-trending segment in western Strathy Township, coincident with the concentration of gold occurrences. That is, the same zone of extension which is the locus of most of the gold occurrences is also the locus of hydrothermal carbonate input.

SUMMARY

The Net Lake-Vermilion Lake Zone of Deformation forms a ramp-like structure which separates the Lower and Middle Volcano-sedimentary Packages, along which the lower part of the Middle Volcano-sedimentary Package is apparently removed. This may imply that the Lower and Middle Volcano-sedimentary Packages are structurally juxtaposed and, hence, their temporal and genetic relationships remain obscure. Virtually all gold occurrences occur within the northeast-trending segment of the Net Lake-Vermilion Lake Zone of Deformation in western Strathy Township. This segment of the deformation zone is interpreted as a dilational jog, which experienced a component of extension during simple shear. These two characteristics of the Temagami Greenstone Belt have important implications for Archean stratigraphic analysis and gold exploration.

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32. Project Number 88–23. Field Investigations at the United Asbestos Deposit, Midlothian Township, District of Timiskaming

D.S. O'Hanley

Postdoctoral Fellow, Department of Mineralogy, Royal Ontario Museum, Toronto.

INTRODUCTION

The largest and most thoroughly studied chrysotile asbestos deposits consist of cross fiber chrysotile asbestos, in which the fiber is oriented at a high angle to the vein wall. In these deposits, the fiber fills fractures that often appear to form a random pattern. On close inspection, however, it is possible in many deposits to establish, from cross-cutting relationships, a definite sequence of fractures and veins. It is then possible to use the fiber orientations to determine the stresses that controlled development of the fractures (O'Hanley 1988).

Chrysotile asbestos deposits in the Abitibi Greenstone Belt are spatially related to the Destor–Porcupine and Kirkland Lake–Larder Lake breaks (Kretschmar and Kretschmar 1986). This project was initiated to determine if fiber orientations in these deposits could be related to these or other structures.

The United Asbestos Mine in Midlothian Township (Figure 32.1) was selected as a first test site. The mine, which is approximately 26 km west of Matachewan, was exploited by open pit operations for two years from 1975 to 1977.

REGIONAL SETTING

Previous geological mapping in the area has been done by Bright (1970, Halliday and Midlothian townships) and Junnila (in preparation, Yarrow and Doon townships). Kretschmar and Kretschmar (1986) included the United Asbestos Mine in their study of the asbestos, talc, and magnesite deposits of the Timmins–Kirkland Lake area.

The United Asbestos Mine is located in the eastern portion of the Halliday rhyolite dome (Bright 1970), which is largely composed of dacitic to rhyolitic metavolcanics in a central area, surrounded by andesitic to dacitic metavolcanics. Ultramafic and mafic sills and stocks intrude the outer strata of the dome. Lithological trends within the dome are generally east–west, and there is evidence of an east–trending isoclinal fold at the Stairs (gold) Mine, which is located 5 km north of the United Mine. A major, east–trending lineament, which has a surface expression in a zone of highly carbonatized metavolcanics and has been interpreted as a fault (E.G. Bright, Geologist, Ontario Geological Survey, personal communication, 1988), extends south of Rhyolite and Dumbell lakes, immediately west of the mine. This lineament is parallel to the assumed trace

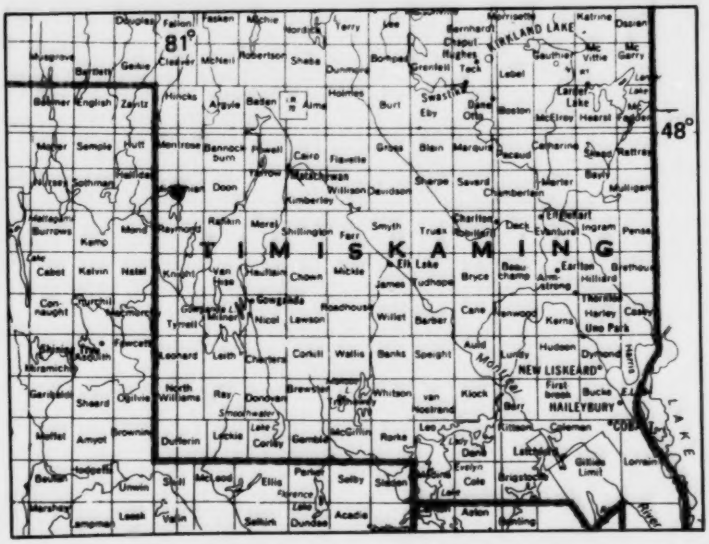

Figure 32.1. *Location map of the study area. Scale: 1:1 584 000 or 1 inch to 25 miles.*

of the Kirkland Lake Break beneath Huronian metasedimentary rocks south of the mine.

GEOLOGY OF THE UNITED ASBESTOS MINE

The United Asbestos Mine occurs within a differentiated mafic/ultramafic complex that is surrounded by dacite flows (Kretschmar and Kretschmar 1986). Kretschmar and Kretschmar proposed the name Lloyd Lake Complex for this rock suite, and that name is used in this report. The Lloyd Lake Complex strikes east–west and dips steeply north on the northern side of Lloyd Lake.

Two east–trending orebodies were defined from interpretation of diamond–drill core (Kretschmar and Kretschmar 1986). The north body consists of the east, north, and west zones, with the north zone situated between the west and east zones. The east and north zones were quarried when the mine was operating, but only trenches were dug in the west zone. The south body, or south ore zone, extends underneath Lloyd Lake, but can be seen in outcrop south of the north ore zone on the northern shore of Lloyd Lake. No mining occurred in the south ore zone.

Exposures in the east and north zone quarries were used for this preliminary investigation. The vegetation had been cleared from the west zone, but it became apparent during the study that the rock has been intensively weathered into spheroidal blocks. As a result, most of the rock is not useful for structural studies, although lithologies could still be recognized from freshly broken samples.

The Lloyd Lake Complex consists of at least two differentiation cycles. The lower cycle consists of a lower dunite; an upper dunite, which contains peridotite pods ranging from 2 by 10 cm to 10 by 50 cm in size; and a peridotite with sporadic, 2 to 3 cm pyroxene megacrysts enclosing olivine. The upper cycle contains a dunite with oriented pyroxene laths; a peridotite with 2 to 3 mm orthopyroxenes that impart a "salt and pepper" texture to the peridotite; and a gabbro unit with pods of pyroxenite that comprise the top of the second cycle and the top of the Complex. This sequence was found throughout the north orebody; therefore, the Lloyd Lake Complex is intact on the northern shore of the lake. No investigations were carried out on the southern shore.

Shear zones can be differentiated from spheroidal weathering surfaces because slip surfaces have some type of slickensides on them: either slickensides, striations, or slickenfiber. The shear zones cause only minor disruption of the Complex. East–trending, north–dipping faults were found in the east and west ore zones, whereas north– to northeast–trending, northwest–dipping faults were found in the north ore zone. Both sets of faults exhibit evidence, based on cleavage relationships, of reverse motion.

VEIN SETS AT THE UNITED ASBESTOS MINE

Several types of veins were found during this study based on appearance and mineralogy. Magnetite veins are 0.5 to 1.0 cm wide and consist predominantly of magnetite. Green veins consist of an apple–green serpentine. Magnetite/green veins consist of both magnetite and green serpentine. Wispy asbestos veins are generally 0.01 to 0.5 cm wide. They occur as clusters of veins 1 to 2 cm wide and spaced 2 to 3 cm apart. Asbestos/magnetite veins are 0.3 to 1.5 cm wide and consist of asbestos with magnetite partings generally in the middle of the vein.

The wispy asbestos veins, which are found in the basal dunite, are the oldest vein set based on cross–cutting relationships. They are cut by north–trending magnetite veins and by northeast–trending, northwest–dipping asbestos/magnetite veins. Cross–cutting relationships among the asbestos/magnetite veins indicate that the oldest asbestos/magnetite veins can be assigned to the wispy asbestos vein set based on location and orientation. However, they appear to be spatially related to faults, whereas the wispy veins do not. The asbestos/magnetite veins are found in the upper part of the dunite and the peridotite of the lower cycle. No asbestos veins were found in the upper cycle. The ore zone corresponds to the distribution of the asbestos/magnetite veins based on the geological map of Kretschmar and Kretschmar (1986). The ore zone, which is bounded by faults, includes some of the wispy veins as well. The wispy veins disappear just south of the mine road, south of the east ore zone quarry, and then reappear in outcrop that corresponds to the south ore zone.

The model that describes asbestos vein formation identifies the asbestos veins as pinnate fractures (Hancock 1985) associated with the faults (O'Hanley 1988). Using maxima for asbestos/magnetite vein orientations (veins: 291°/54°; fault: 258°/51°) in the east ore zone, and for magnetite/green veins (veins: 214°/53°; fault: 217°/64°) in the north ore zone, and an angle of internal friction of 30° for serpentinite (Raleigh and Paterson 1965) yields the orientation of the local stress field. In these cases, the orientations are σ_1=106°/16°; σ_2=357°/50°; σ_3=202°/36°, and σ_1=325°/36°; σ_2=204°/36°; σ_3=112°/53°. These results suggest that the asbestos/magnetite veins formed during a northwest–southeast compression, with σ_1 closer to the horizontal than to the vertical.

CONCLUSIONS

The United Asbestos Mine is located in a differentiated sill, called the Lloyd Lake Complex. Early wispy asbestos veins pre–date virtually all other vein sets, and are spatially restricted to a portion of the lower dunite in the Complex. The asbestos/magnetite veins are genetically related to fault motion. Chrysotile fiber and vein orientations indicate that the veins formed in a northwest–southeast stress field, with σ_1 closer to horizontal than to vertical.

This brief reconnaissance suggests that cross fiber orientations in chrysotile asbestos deposits in the Abitibi greenstone belt may be useful in indicating the stress fields related to major structures in the belt. However, before this technique can be more widely applied, the relationships of the deposits to these major structures must be better defined.

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33. Project Number 88–06. Geological Setting of Gold Mineralization in the Southern Swayze Belt

G.M. Siragusa

Geologist, Precambrian Geology Section, Ontario Geological Survey, Toronto.

INTRODUCTION

Recent and current exploration activity in the Swayze belt has improved exposure at several gold occurrences. Three such occurrences were examined during the 1988 field season taking advantage of this increased exposure. The purpose of this work is to document the lithological and structural features characteristic of the occurrences, and to define the alteration associated with them. These data will contribute to the continuing program of the Ontario Geological Survey to define the geology of Archean gold deposits (Colvine *et al.* 1988), and, more specifically, will aid in exploration for such deposits in the Swayze belt.

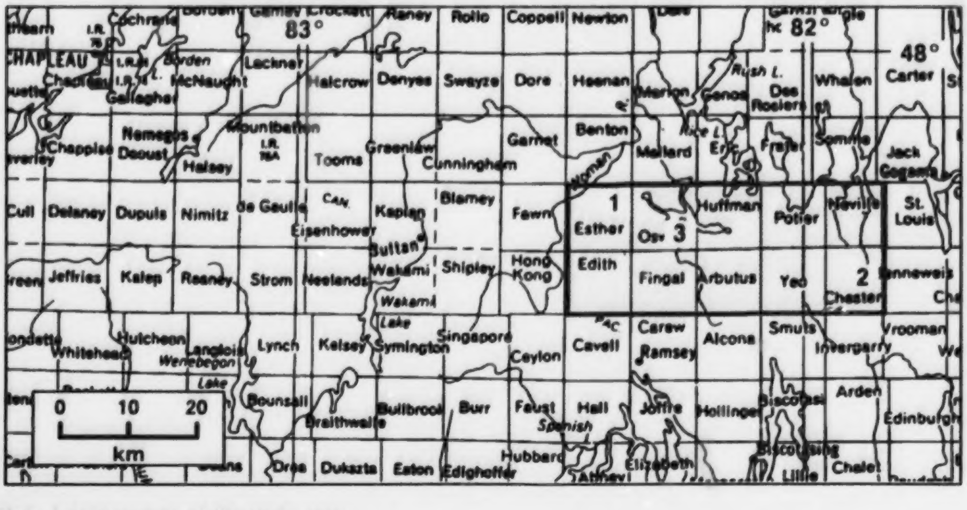
REGIONAL SETTING

The three occurrences studied are in Esther, Osway and Chester townships (Figure 33.1). These townships are underlain by Archean metavolcanic and metasedimentary rocks of the Swayze belt (Siragusa, in preparation). These rocks, largely of greenschist metamorphic rank, have been deformed by an east–southeast-trending synclinorium. The outer limbs of the synclinorium consist of undifferentiated tholeiitic metavolcanics, and the core contains younger calc-alkaline metavolcanics and polymictic metaconglomerate. Two of the occurrences studied, in Esther Township (Longitude 82°21′57″W and Latitude 47°39′35″N) and in Osway Township (Longitude 82°14′20″W and Latitude 47°37′15″N), occur within these greenschist grade rocks. The third occurrence, in Chester Township (Longitude 81°53′30″W and Latitude 47°33′20″N), is in a higher grade, migmatitic fringe that surrounds regional granitoid rocks south of the greenstone belt.

ESTHER TOWNSHIP OCCURRENCE

This occurrence has been the focus of exploration work since 1928, when a shaft was sunk on the property by A. Burton. Siragusa (1980, Occurrence 16) summarizes this work to the end of 1979.

In 1983 and 1984, a significant volume of surface exploration and diamond drilling was carried out in the area by Canadian Nickel Company Limited (Canico), which subsequently dropped the property. This work resulted in a preliminary estimate of ore reserves of 17 460 t at 10.09 ppm, and 176 170 t at an unspecified grade (Canadian Nickel Company Limited 1985). This reserve is for the "Shaft Zone", which is in the vicinity of the 1928 shaft. Canico reported that the mineralization in the Shaft Zone is controlled by folding and extends east (known as the East Zone) for approximately 1 km from the shaft. Gold values were reported to decrease eastward.


83°
82°
48°
CHAPLEAU
Cochrane
I.R. 75
I.R. 74
I.R. 61
Borden
L.
McNaught
Gallagher
Chapleau
Lackner
Halcrow
Denyes
Swayze
Dore
Heenan
Marion
Genoa
Rush L.
Des Rosiers
Whalen
Carter
Raney
Rollo
Coppell
Newton
Nemegos
Chapple
Deoust
Halsey
Mountbatten
I.R. 76A
Tooms
Greenlaw
Cunningham
Garnet
Benton
Mallard
Rice L.
Eric
Frazer
Somme
Jack
Cogawa
Cull
Delaney
Dupuis
Nimitz
de Gaulle
CAN.
Eisenhower
Kaplan
Blamey
Fawn
1
Esther
Osway
3
Huffman
Potier
Neville
St. Louis
Jeffries
Kalep
Reaney
Strom
Neelands
Sultan
Wakami
Shipley
Hong Kong
Edith
Fingal
Arbutus
Yeo
2
Chester
Wakami
Lake
Whitehead
Hutcheon
Langlois
Wenebegon
Lake
Lynch
Kelsey
Symington
Singapore
Ceylon
Cavell
Carew
Ramsey
Alcona
Smuts
Invergarry
Vrooman
Arden
Bounsall
Braithwaite
Bullbrook
Burr
Faust
Spanish
Hall
Joffre
Hollinger
Biscotasi
Edinburgh
Dres
Dukszta
Eaton
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Hubbard
Elizabeth
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Little
Chalet
0
10
20
km

Figure 33.1. *Location map of the study area.*

The Shaft Zone and the East Zone are presently well exposed because of the extensive stripping done by Canico. The mineralization in both zones is hosted by carbonatized and, to a lesser extent, silicified mafic metavolcanics. It consists of disseminated to massive arsenopyrite, pyrite, and pyrrhotite, found mainly in quartz.

In the Shaft Zone, the mineralized quartz occurs in folds plunging westward at shallow angles. Folding near the Shaft Zone is also indicated by the pattern of two intersecting cleavages in unmineralized basalt. One cleavage (S_1) is pervasive and defines the folds; the second (S_2) is an axial planar cleavage which variably offsets or truncates S_1, but does not obliterate it.

The East Zone is linear, narrower than the Shaft Zone, and characterized by a stronger development of S_2. Drawn-out folds of mineralized quartz, or remnants of such folds, occur in parts of the zone, but outcrops in which plunge attitude can be measured are rare. In two cases, the plunge was found to be shallow easterly. Incipient transposition of bedding was noted in metasediments in contact with basalt at the southern edge of the East Zone. Details such as attenuation of folded beds to a thickness of a few millimetres are preserved in the metasediments, in contrast with the obliteration of primary features in the nearby basalt.

OSWAY TOWNSHIP OCCURRENCE (JEROME MINE)

Gold was discovered at this property in 1938 by Bert Jerome. Subsequent exploration and development (summarized in Siragusa 1980, Occurrence 1) culminated in the production of 56 878 ounces of gold and 15 104 ounces of silver (Brown 1948) from the Jerome Mine during the period from 1941 to 1943. When operations ceased in 1945, the ore reserve was 344 000 tons averaging 0.19 ounce gold per ton after dilution (Canadian Mines Handbook 1946, p.159).

An exploration program, comprising mine rehabilitation and surface diamond drilling, is currently being carried out by Muscocho Explorations Limited in joint venture with Jerome Gold Mines Corporation. In September 1988, the headframe, shaft, and hoist were operational and dewatering was completed to a depth of 525 feet. Diamond drilling totalled 45 000 feet (J. Mallard, Exploration Geologist, Muscocho Explorations Limited, Jerome Mine site, personal communication, 1988).

The presently known gold mineralization on this property comprises two zones: 1) the North or Main Zone, and 2) the South Zone which extends a few hundred feet south of the North Zone. The underground workings are in the North Zone. The South Zone has long been known, but until now, has received no significant exploration. Most of the current drilling has been concentrated on the South Zone, and drill sections indicate that it consists of three subzones. Data released in June 1988 indicate that drilling as of then had increased the known ore reserve on the property to 437 320 tons grading 0.193 ounce gold per ton (Jerome Gold Mines Corporation, 1988 Semi-annual Report to Shareholders).

The best ore found in the area is auriferous blue quartz (Brown 1948; Moorhouse 1951), which is colloquially referred to at the mine site as "the deep blue". In the North Zone, this quartz occurs at, or close to, sheared and altered contacts of clastic metasediments with fine-grained syenite. Moorhouse (1951) named this syenite the Jerome Porphyry. He described the different alteration processes that had affected the metasediments and referred to their effect as "porphyritization". The North Zone is also affected by two sets of post-vein faults and by a later silicification which occurs as white quartz. These features, their temporal relationships, and economic implications were also described in detail by Brown (1948).

Only the 200-foot level of the underground workings was examined during the present study. At this level, the dark blue, almost black, quartz occurs as solid, 4 to 8 inch thick veins, and as abundant inclusions in a matrix of white replacement quartz containing little carbonate. These two modes occur adjacent to each other, with the second type apparently comprising most of the thickness of the resulting unit. Only minor disseminations of sulphide mineralization (pyrite and chalcopyrite) were noted. Molybdenite is reportedly present in the blue quartz (M. Rosatelli, Geologist, Muscocho Explorations Limited, Jerome Mine site, personal communication, 1988).

A unit of dark quartz, composed of both the vein and inclusion types, occurs 60 feet east of the crosscut leading to the shaft on the 200-foot level. This unit trends southeast, dips steeply southwest, and has an exposed thickness of up to 3 feet. It can be seen in the west wall of a raise from the 350-foot level to extend downward, with uniform thickness, for at least 35 feet. Further below, the raise merges with one of the main stopes between the 200- and 350-foot levels, indicating that a significant volume of this dark quartz unit was mined. It is, therefore, presumably representative of the ore in the North Zone and was sampled for geochemical and petrological studies.

The Jerome Porphyry is exposed in the hanging wall of the quartz unit approximately 30 feet west of the raise opening. Here, the porphyry is sheared, contains specularite (which is locally conspicuous), and shows slickensides that dip shallowly eastward.

CHESTER TOWNSHIP OCCURRENCE

This occurrence is along strike from the (former) Strathmore Shaft, a gold prospect where limited underground work was done in the 1930s and 1940s. Data available for these occurrences to 1980 are summarized in Siragusa (1981).

Both surface and underground exploration is presently being carried out by Chesbar Resources Incorporated in joint venture with Murgold Resources Incorporated. The estimated ore reserve as of June 1988 was 423 546 tons averaging 0.223 ounce gold per ton (Murgold Resources Incorporated, News Release, June 23, 1988). The current underground exploration is utilizing a decline, the portal of which is located about 600 feet north of a small lake locally known as Arethusa Lake. The decline is 16 feet wide, 10 feet high, and has a gradient of 12.5 percent. There are two ramps, one to the southeast (3500 feet long) and one to the northwest (2000 feet long), which are connected by a semicircular ramp extending 1900 feet from the portal. At present, the shorter ramp ends at a depth of 515 feet below the portal and the longer ramp ends 150 feet east of, and 300 feet below, the (former) Strathmore Shaft. To date, most drifting and crosscutting has been done at the 150–, 200–, and 400–foot levels in the western half of the decline and between the two ramps.

Development at the 150– and 400–foot levels is mainly in mafic rocks which vary from fine–grained chlorite schist near the mineralization to medium–grained gabbroic–textured amphibolite some distance from the mineralization. The amphibolite is in both sharp and gradational contact with granitic rocks on the 200–foot level and in an outcrop on the eastern side of the portal at surface. The amphibolite is locally known as the "gabbro–diorite" or "gabbro–diorite complex". It is interpreted in this study to be a large mafic enclave in the migmatitic fringe bordering the metavolcanic belt of greenschist rank north of the property. The soft chlorite schist is attributable to retrograde metamorphism of the amphibolite.

Mineralization consists of disseminated to massive chalcopyrite and pyrrhotite, dominantly in quartz veins. Visible gold was seen in drill core. Mineralized quartz veins are a few inches to about one foot thick, trend east–southeast, and dip steeply north. They occupy the centres of narrow linear shear zones and can be affected by pinch and swell structures or boudinage. However, exceptionally straight veins of virtually constant thickness are also present (e.g. Drift 7 East, 200–foot level).

CONCLUSIONS

The geology of each of the three gold occurrences presents problems that will be addressed in continuing studies.

At the Esther Township occurrence, the S_1 and S_2 cleavages are interpreted to result from a single event, i.e. progressive deformation resulting from regional shortening of the belt along the northeast trend. S_1 is dominant in the Shaft Zone and S_2 is dominant in the East Zone. If the author's interpretation is correct, ore grades developed during early deformation (Shaft Zone) could have been affected by later deformation (East Zone). This possibility is consistent with the eastward decrease in gold grades reported by Canico (1985).

The origin of the blue quartz at the Jerome Mine remains unknown. Brown (1948) reported that the blue quartz occurs at the contact of the Jerome Porphyry with metasediments; this observation is supported by the limited field evidence seen during the 1988 study.

The vein system being explored at the Chester Township occurrence has a remarkable lateral continuity. It comprises silicified shear fractures that extend through both leucocratic and melanocratic domains of the host migmatites. Shearing and silicification are virtually unaffected by changes in lithology of the migmatites. The ore, however, appears to occur mainly where the veins intersect the "gabbro–diorite". This could imply that the economically significant gold mineralization is, at least in part, lithologically controlled

ACKNOWLEDGMENTS

J. Perry (Project Geologist, Canadian Nickel Mines Limited) and C. McAlpine (President, Murgold Resources Incorporated, Toronto) provided data on the occurrences in Esther and Chester townships, respectively. D. Lebenin (Surveyor), R. Hill (Mine Geologist) and D. O'Suillebhain (Surface Geologist) of Chesbar Resources Incorporate provided substantial assistance in the field, as did J. Mallard (Exploration Geologist) and M. Rosatelli (Geologist) of Muscocho Explorations Limited.

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34. Project Number 83–50. Hemlo Tectono–stratigraphic Study, District of Thunder Bay

T.L. Muir

Geologist, Precambrian Geology Section, Ontario Geological Survey, Toronto.

INTRODUCTION

This season saw the continuation of a multiple–year mapping project which is intended to provide a synthesis of lithological, structural, and metamorphic data for the environs of the Hemlo Gold–Molybdenum Deposit. Mapping was conducted at a scale of 1:5000, covering an area of about 10 km² (*see* Figure 34.1).

Work during the season concentrated on four areas of interest (*see* Figure 34.2): a) the terrain to the south of the Hemlo Fault (which lies just south of the deposit), mainly along tailings and effluent access roads created since 1983 by the companies mining the deposit (scale 1:5000); b) the terrain north and northwest of the Page–Williams Property (scale 1:5000); c) the area of the North Zone, Golden Sceptre Property (scales of 1:5000 and 1:1000); and d) the "C300" Zone of the Page–Williams Property, where a recently exposed part of the ore zone was mapped in detail (scale 1:250). A detailed map of the "C300" Zone is included in this summary. The structural complexity of the other areas mapped in 1988 is similar to that shown in previously published maps (*see* Muir 1986; Muir and Elliott 1987). The maps for these other areas are presently being compiled, and do not appear here.

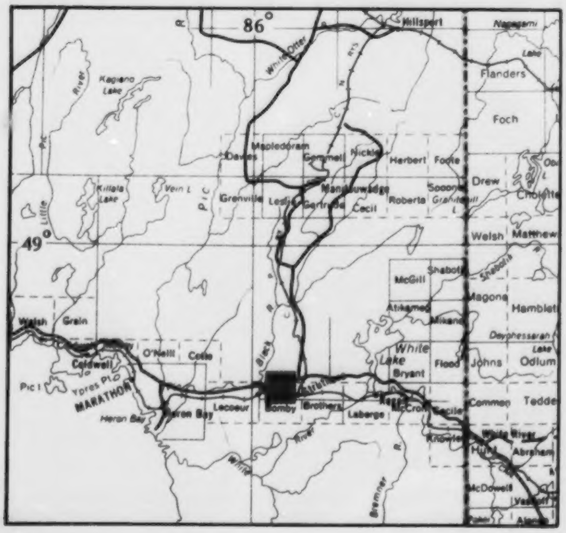
86°
49°
Hillsport
Nagagami
Lake
Flanders
Foch
River
Kagiano Lake
Pic
White Otter
Mapledoram
Davies
Gemmell
Nickle
Herbert
Foote
Drew
Killala Lake
Vein L
Pic
Grenville
Leslie
Gertrude
Cecil
Roberta
Manitouwadge
Welsh
Matthew
Shabotik
McGill
Magone
Hamblet
Atikameg
Mikano
Welsh
Grain
Dayohessarah Lake
White Lake
Bryant
Flood
Johns
Odlum
O'Neill
Cotte
Coldwell
Pic I
Ypres Pt.
MARATHON
Heron Bay
Heron Bay
Lecoeur
Bomby
Brothers
Laberge
McCron
Cecile
Common
Tedder
Black
White River
Knowles
Hunt
Abraham
McDowell
Bremner
White
River

Figure 34.1. *Location map for the Hemlo area, District of Thunder Bay. Scale 1:1 584 000 or 1 inch to 25 miles.*

The general geology (lithology and structural elements) of the map area, or parts of it, has been described previously by Muir (1982, 1985, 1986), Muir and Elliott (1987), Patterson (1984, 1986), Hugon (1984, 1986), Hugon and Schwerdtner (1988), Brown *et al.* (1985), Quartermain (1985), Valliant *et al.* (1985), Valliant and Bradbrook (1986), Burke *et al.* (1986), Kuhns (1986), Kuhns *et al.* (1986), Walford, Weicker, and Guthrie (1986), and Walford, Stephens, Skrecky, and Barnett (1986). Various, and often conflicting, conclusions about the history of the deposit have resulted from work at the exploration and mining scales. The geological history of the deposit and its environs is unquestionably complex and many aspects of its geology are equivocal. With this in mind, the following aspects of the 1988 season's work are presented.

TERRAIN SOUTH OF THE HEMLO FAULT

GENERAL GEOLOGY

The geology of the area mapped in 1988 (Figure 34.2) prompted comparison with the lithologies and structural features found north of the Hemlo Fault (*see* Muir and Elliott 1987). This was of particular interest given the possibility that the fault is a significant structural discontinuity (Corfu and Muir 1988; Muir *et al.* (1988), based on limited U–Pb geochronological data.

There are local similarities in lithologies between the two terrains, yet significant differences are also present. The rocks to the south of the Hemlo Fault tend to be more recrystallized, particularly with respect to amphibole, individual crystals of which commonly range from 2 to 10 mm long. There is an abundance of rocks which range from mafic to intermediate in composition. The generally well–developed layering has resulted in rocks of a gneissose character. The distribution of lithologies in detail is fairly complex and does not indicate a simple layer–cake stratigraphy.

Feldspathic Volcaniclastic Deposits

A major rock type south of the Hemlo Fault consists of what were feldspathic volcaniclastic deposits, presumably originally composed of sand–size particles. Coarser clastic rocks are rare. The volcaniclastic

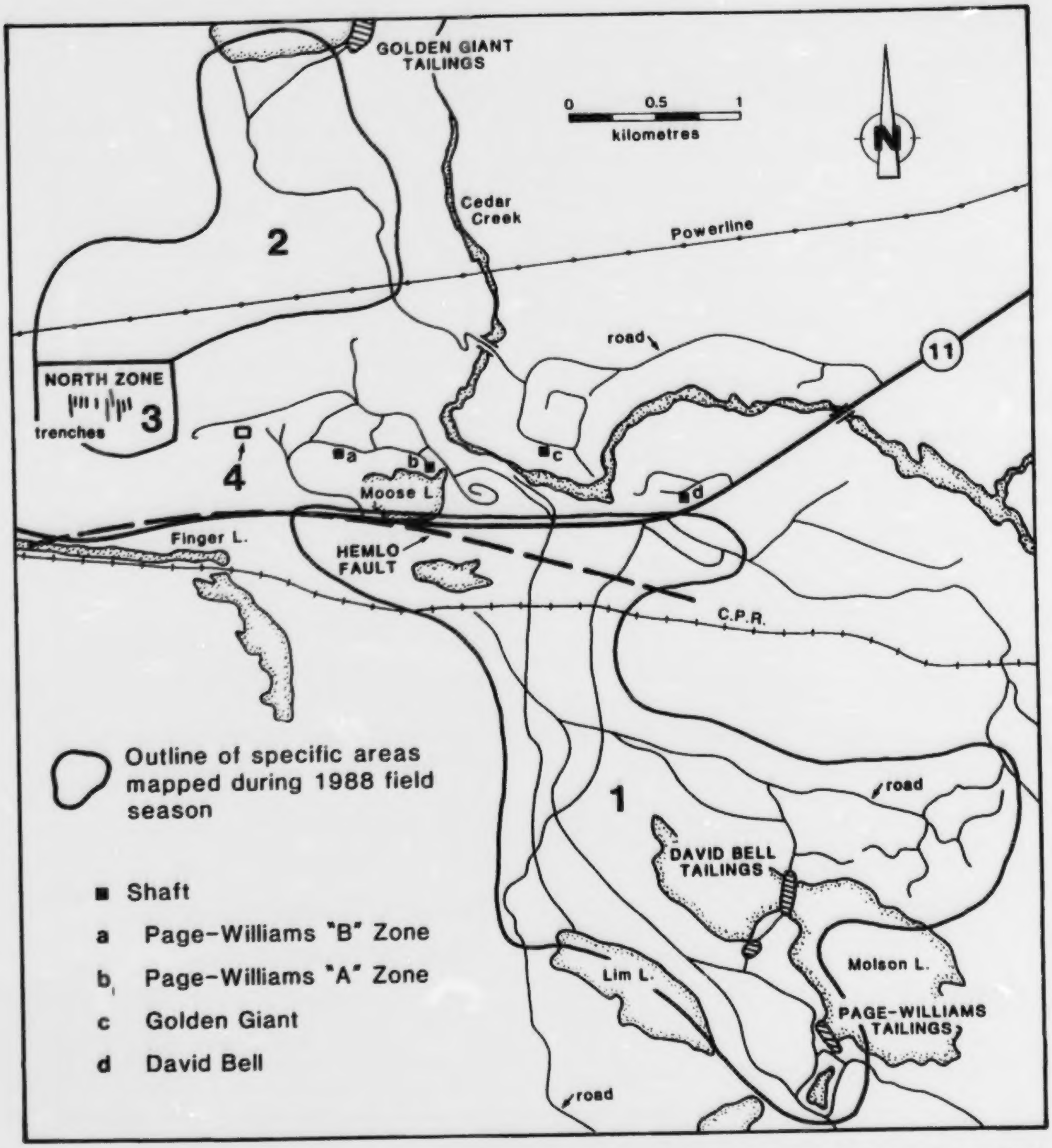
GOLDEN GIANT TAILINGS
0
0.5
1
kilometres
N
Cedar Creek
Powerline
2
road
11
NORTH ZONE
trenches
3
4
a
b
c
d
Moose L.
Finger L.
HEMLO FAULT
C.P.R.
Outline of specific areas mapped during 1988 field season
■ Shaft
a Page-Williams "B" Zone
b Page-Williams "A" Zone
c Golden Giant
d David Bell
1
road
DAVID BELL TAILINGS
Molson L.
Lim L.
PAGE-WILLIAMS TAILINGS
road

Figure 34.2. *Location of four main areas of mapping this season: 1) Terrain South of the Hemlo Fault; 2) Terrain North and Northwest of the Page-Williams Property; 3) Area of the North Zone, Golden Sceptre Property; 4) "C300" Zone, Page-Williams Property.*

rocks, particularly the coarser varieties, locally contain quartz crystals (much less than 1 percent) which are coarser grained than grains in the surrounding, largely quartzo-feldspathic matrix. Lithological and compositional layering, likely related to bedding, is generally from 0.5 to 5 cm thick. These features are essentially equivalent to those of units north of the Hemlo Fault. Locally, concordant, recrystallized, tabular, mafic "bodies" are present and may be either amphibole-rich layers (locally know as "calc-silicate" layers) or gabbroic dikelets. Both rock types occur locally, as is also the case north of the Hemlo fault.

Pyritic Quartz–Eye Sericite Schist

Of exploration interest is a unit, centred about 1.9 km south of the David Bell Mine turnoff on Highway 17, which strikes at about 300°, and is traceable for almost 1 km. The unit consists mainly of feldspar, sericite, and quartz, and contains about 10 percent monocrystalline to polycrystalline quartz "eyes". It generally weathers to a rusty brown because of fine– to very fine grained disseminated pyrite. Locally, small, sparse, green mica lenses are present. The unit is well foliated and locally quite schistose. It is interpreted to be locally interbedded with foliated, feldspar–quartz–biotite metasediments, although relatively sharp lithological contacts in places resemble an intrusive relationship for the quartz "eye" unit. The overall similarities between the quartz "eye" unit and felsic quartz–porphyritic volcanic and volcaniclastic units north of the Hemlo Fault suggest that at least some of the units north and south of the fault could be correlative. The presence of green (vanadium–bearing?) mica, pyrite, sericite, and quartz "eyes" is similar to some of the characteristics of the ore–bearing altered rock in parts of the Hemlo Deposit.

Aluminous Rocks

A unit of aluminous rocks is centred about 0.35 km south of Moose Lake, strikes at about 280°, and is traceable for almost 1.2 km. The unit is conspicuous for the presence of 5 to 10 percent garnet in a feldspar, biotite, and quartz matrix. Of particular interest in the western end of its traceable extent is the presence of staurolite–bearing layers (up to 5 percent staurolite), some possibly containing anthophyllite. This assemblage compares favourably with biotite–garnet–staurolite–anthophyllite–bearing metasediments which lie about 1.5 km to the east, and as little as 150 m (measured horizontally) structurally above the ore zone. The unit is interpreted to be bounded by schistose, biotite–quartz–feldspar metasediments.

Mafic to Intermediate Rocks

The mafic to "intermediate" rocks fall into two categories: those entirely composed of mafic and epidote–rich layers; and those with various proportions of feldspathic layers. The latter category consists of rocks which may initially have been composed of mixtures of felsic (feldspathic) and mafic sediments. Alternatively, the compositional variations may be partly or wholly a tectono–metamorphic feature. On an outcrop scale, the proportions of each may range from 30 to 70 percent. These rocks are, as such, difficult to classify, and the lack of any primary features exacerbates the problem. These rocks appear to be thickest south of the Canadian Pacific Railway in the area south of Moose Lake. They are present elsewhere, spatially associated with either feldspathic volcaniclastic rocks or gneissic amphibolites.

Mafic Rocks

The mafic rocks are largely gneissic amphibolites. Although compositional layering is locally very weak to absent, it is generally moderately to well developed, and is expressed by variations in grain size, texture (grain shape), and relative abundances of feldspar, epidote, biotite, and amphibole (Photo 34.1). Also present are rare to numerous, layer–parallel, thin, quartzo–feldspathic veinlets. The layers range in definition from sharp to diffuse, in thickness from 0.1 to 100 cm, and in length from one to at least several metres. Locally, coarse–grained, virtually unlayered units within the gneissic amphibolites are up to 2 m thick and may represent mafic dikes or sills. In one location, amphibole–rich layers enclose segments of amphibolite, and are interpreted to be possible recrystallized, deformed, pillow selvages. Otherwise no volcanic features were identified in this area.

"Poker Chip" Amphibolite

A particular unit (or units), is of interest because it serves as a marker of sorts. The rock is an amphibolite, with varying degrees of layering development, and contains conspicuous "felsic" lenses. This rock type has been colloquially termed the "poker chip" unit (J. Grant, Geologist, Esso Minerals Canada Limited, Toronto, personal communication, 1988). The felsic lenses range from 1 to 5 cm long (horizontally) and from 1 to 50 percent in abundance. They appear to be elongated (lineated), where this can be observed. In general, length–to–width ratios in outcrop surfaces range from 2:1 to 10:1. In less deformed examples, subangular shapes can be discerned. The lenses weather white, and in fresh surfaces range from white to pale green. Various concentrations of the lenses locally define crude layering, which suggests up to 4 separate units; or one unit repeated by folding or tectonic (fault) repetitions; or some combination of the above. The lack of continuity of units, distinctive assemblages of units, and evidence for large–scale folds, precludes a preferred choice of interpretation, although large–scale, layer–parallel lineaments in this area offer evidence for possible fault repetition. This rock type is the same as reported by Muir (1982) and Siragusa (1984a, 1984b, 1985) and is interpreted to extend from Lake Superior to just west of Animons Lake (south–southeast of White Lake), a strike length of some 64 km.

At least three possible origins for this rock can be considered: a) plagioclase–phyric mafic (tholeiitic) flow(s) or sill(s); b) variolitic flows(s) or sill(s); or c) mafic tuff with felsic lapilli. The third interpretation, put forth by Muir (1982), is rejected here as unlikely, particularly in light of the apparent strike extent. The second interpretation, put forth

Photo 34.1. *Gneissic amphibolite showing: quartzo-feldspathic stringers and felsic dikelet; and F_3 Z-fold and crenulation cleavage. The Z-fold is similar to a kink fold; the crenulation is confined between two parallel boundaries.*

by Siragusa (1984a, 1984b), is difficult to reject outright because the generally strong degree of deformation has obscured the original nature of the lenses. However, the first interpretation is preferred because the few weakly deformed outcrops of this rock type in the map area have lenses which resemble saussuritized plagioclase crystals, and because there is a similarity between this rock and known plagioclase-porphyritic flows or sills in other areas.

Primitive Rocks

There are two zones in which rocks having a more primitive origin may occur. One is within gneissic amphibolite in a lineament that lies about 40 m structurally above, and parallels, the volcano-sedimentary granitoid contact near the Page-Williams Mine tailings dam at Molson Lake (Figure 34.2). Here, rocks are variably deformed and altered, and consist of actinolite schist, chlorite-talc-actinolite schist, and biotitite. The first two rock types are also found within the Hemlo Fault Zone. Here, whole rock geochemistry of the first two rock types suggests they are picritic in bulk composition with requisite nickel and chromium contents. The other zone is just northeast of Molson Lake and involves a skarn-like unit within amphibolitic rocks. There are chlorite-, actinolite-, and talc-bearing rocks here, as well as a variably thick unit(s) of coarse-grained garnet and diopside in a white matrix of feldspar(?).

Granitoid Dikes and Complexes

Granitoid dikes (sills?) having thicknesses ranging from 5 to 30 m are present at several localities. The rocks are non-porphyritic, biotite-hornblende granodiorite (field identification), or weakly plagioclase-porphyritic granodiorite. The porphyritic varieties are somewhat similar to some thinner dikes in the area which are akin to porphyritic dikes north of the Hemlo Fault. Although the relatively thick bodies can be found in several localities, there is insufficient exposure to interpret their continuity. Considerable extrapolation between outcrops could be used to join similar units, but the enclosing rocks are different, which would imply discordancy of units.

Locally gneissic, weakly to moderately plagioclase- porphyritic granitoids are present. In one case, there appears to be a gradation from layered, feldspathic rocks to a gneissic variety of the same, suggesting local granitization. Elsewhere, recrystallized amphibolitic rocks are complexly 'mixed' with varieties of amphibole-bearing, quartz-poor granitoids. Hybrid varieties are also present. Intrusive relationships show multiple events of dike emplacement. The composition of the dikes ranges from felsic to mafic. The gneissic and hybrid rock zones are bounded on both sides by rocks of less-altered character, which are not the same everywhere, thus suggesting a discordant relationship to stratigraphy.

The southern extent of the volcano-sedimentary rocks in this area is bounded by the Pukaskwa Gneissic Complex, which consists of well-foliated, plagioclase-porphyritic, biotite-hornblende granodiorite; hornblende quartz diorite; biotite-hornblende granodiorite; and massive aplite and pegmatite, in decreasing relative age. Foliation-parallel dikes within the complex, having a variety of textural and compositional features, tend to be more common within about 100 m of the granitoid/volcano-sedimentary contact.

STRUCTURAL GEOLOGY

In comparing structural features in this area with those north of the Hemlo Fault, various attributes were considered, including the style, orientation, and generation of structures observed. The selection of these attributes was based largely on the work reported by Muir and Elliott (1987) and Muir (1986). The salient features were: a) local, small-scale folding (F_1) of lithological layering and/or bedding; b) moderately steep, west-plunging mineral, dimension (elongation), and S_1/S_2 intersection lineations that parallel, and correspond to, F_2 fold axes, with development of an axial planar cleavage or differentiated layering (S_2), possibly related to a sinistral shear system; c) shallow to moderately steep, lineated, east-plunging porphyroblasts and S_2/S_3 intersection lineations that correspond to F_3 fold axes having "Z" asymmetry, with development of a preferred dimensional orientation of micas, and/or a crenulation cleavage (S_3) related to a dextral shear system, and later, layer-parallel breccias and pseudotachylites; and d) north-northwest- to north-northeast-trending conjugate fractures/faults.

The strike of lithological and compositional layering (S_1) ranges from 280° in the northwestern part of this area, southwest of Moose Lake, to 305° in the southeastern part, at Molson Lake. This reflects the variation in the curvature of the volcano-sedimentary rocks about the Pukaskwa Gneissic Complex. Dips range in the northern part of the area from about 70°N, to about 45°N in the southern part near the Pukaskwa Gneissic Complex. Locally, dips change abruptly and are as shallow as about 20°N.

There are several layer-parallel to subparallel lineaments present, some of which are major; they roughly parallel the volcanosedimentary/granitoid (Pukaskwa Gneissic Complex) contact. Some appear to mark lithological changes on either side, but others do not. No simple model attributing these lithological changes to faults that repeat stratigraphy can be proposed at this stage.

The S_2 cleavage was relatively rarely observed in these rocks. Collectively, orientations both clockwise and counterclockwise to S_1 layering were found, which indicates F_2 folds are present. Just south of the Hemlo Fault, S_2 is clockwise to S_1, as it is to the north of the fault. Cross-sections of units, in trenches blasted for tailings or effluent pipelines, show homoclinal rolls in the layering about generally west- to north-west trending, shallowly plunging axes. These structures explain the locally shallow dips, the general lack of recognized S_2 cleavage, and the similarly plunging mineral and intersection lineations found throughout much of the area. Locally, shallow east-plunging axes and lineations are present. Small-scale, shallowly plunging, S-shaped folds were also locally observed.

The development of the S_3 foliation, with accompanying crenulation of the S_2 fabric, and associated Z folds is very common in the mafic rocks, including many dikes and amphibole-rich (calc-silicate) layers. The feldspathic rocks largely appear unaffected. The S_3 cleavage orientation ranges from about 240° to 300° but is generally from 260° to 280°, with dips ranging from 80°N to 80°S. The F_3 axes plunge east-northeast from 10° to 50°. The crenulation fabric in gneissic amphibolites is locally so strongly developed and has such sharp interlimb angles, that an incipient compositional layering is locally developed parallel to S_3. Elsewhere, the crenulations are essentially confined between parallel boundaries and are similar to large-scale kink folds (Photo 34.1). These zones of ductile crenulation/kink folding locally terminate by pinching out. However, their distribution throughout the outcrop suggests an *en echelon* development. Locally, Z-shaped (F_3?) folds with an amplitude of about 1 m show well-developed, S-shaped, parasitic folds on the short limb. Notwithstanding this development of F_3 S-folds, there are other S folds that appear to be of an F_2 generation.

There are numerous quartzo-feldspathic dikelets (partial melts?) within the gneissic amphibolites, some of which display tight S-shaped folds (F_2?) and more open Z-shaped F_3 folds. Locally, layering in the amphibolites also shows refolded folds. The above features are most evident in the mafic rocks that are within 150 m of the contact with the Pukaskwa Gneissic Complex. A heterogeneous granitoid dike swarm within this zone formed after the refolded folds and dikelets, and before development of F_3. There is a possibility that the rocks in this zone have undergone a somewhat different structural history than those farther north. Alternatively, because dikelets bordering the Cedar Lake Pluton and Cedar Creek Stock also display refolded folds, it may be that progressive, differentiated movement, localized along volcano-sedimentary/granitoid interfaces, can produce these features. However, well away from the Pukaskwa Gneissic Complex can be seen Z-shaped folds with apparent parasitic folds on the larger-scale fold overprinting a smaller, earlier fold, and thus remain enigmatic.

The marginal zone of the Pukaskwa Gneissic Complex is also laden with foliation-parallel granitoid dikes, and locally displays features similar to brittle-ductile F_3 folds/fault structures with dextral offset, described previously by Muir (1985) and Hugon (1986), which are also common throughout the supracrustal rocks.

Later conjugate fault sets trending north-northwest and north-northeast, with dextral and sinistral offset respectively, occur locally.

TERRAIN NORTH AND NORTHWEST OF THE PAGE-WILLIAMS PROPERTY

GENERAL GEOLOGY

Metasediments

This area (Figure 34.2) is underlain mostly by turbiditic deposits of metasandstone and metasiltstone, which locally display primary features such as grain size grading, clast grading, and rip-up clasts. Interbedded conglomeratic deposits (turbiditic?) are locally present. The rocks range from highly feldspathic (Photo 34.2) to moderately biotite/amphibole-bearing. The feldspathic varieties commonly have sparse, distinct, quartz grains, and are interpreted as being volcaniclastic in origin, related to quartz- and feldspar-phyric pyroclastic rocks in the vicinity of the Hemlo Deposit. They may have been deposited in a more distal, turbidite fan environment. The other more mafic varieties are, at least in part, of similar origin, but may have an additional component of undetermined provenance. Quartz crystals may be present, and are slightly more common in the rudaceous deposits. Biotite to hornblende ratios range considerably; locally either mineral may be absent. Metaconglomerates tend to have matrixes equivalent to medium- to coarse-grained wacke. Clasts are largely feldspar- or quartz-feldspar-phyric. Locally, several units of granule to pebble conglomerate are traceable for about 0.4 km. They have a mafic to intermediate amphibole-bearing matrix, and are distinct from virtually all other units. The clasts are heterolitic but are generally felsic with less common intermediate compositions.

Basalt

In the northern part of the area, mapped to the south of the Golden Giant Mine tailings lake, is a unit of pillowed and 'massive' tholeiitic basalts. These rocks are locally amygdaloidal. Where shapes have been moderately well maintained, top directions give consistent indications to the north. This relationship is consistent with the lower contact of the mafic metavolcanics, which displays incompletely but intimately mixed amphibolite and garnet-feldspar-biotite material, in that it may represent soft-sediment deformation that occurred when the flows overrode the sediments.

STRUCTURAL GEOLOGY

Lithological layering (S_0, S_1) and S_2 cleavages change strike considerably in this area from northwest, in the east, to west-northwest, in the west. This reflects the presence of the Cedar Creek Stock just to the east, and strongly suggests that the stock postdated the development of F_2 folding, or, at the least, intruded during the later stages of F_2 folding.

There is a major northwest-plunging, antiformal, F_2 fold centred on the Page-Williams Property, shown in Patterson (1984); described in Muir (1985), Walford, Weicker, and Guthrie (1986), Walford, Stephens, Skrecky, and Barnett (1986); and discussed in Muir and Elliott (1987). The axis of this fold has now been traced further to the northwest onto adjacent properties (Golden Sceptre Resources Limited, Interlake Development Corporation). Units on the south limb of this fold have both S_2 and S_3 oriented counterclockwise with respect to S_0/S_1. Locally, both fabrics can be identified (Photo 34.2). An adjacent, synformal, F_2 fold axis to the

Photo 34.2. *Bedded volcaniclastic metasediments on the south limb of a large scale, west-closing, F_2 fold. View shows S_0 (S_1), S_2 (axial planar cleavage), and S_3 (flattening fabric during dextral shear (F_3) event).*

northeast can be inferred from the present mapping and is crudely traceable for about 1 km.

The strike of the S_3 foliation ranges from about 240° to 300° but is generally at 270°±10°. Dips generally range from 60°N to 80°N but locally may be vertical. Crenulation cleavage is uncommon (cf. area to south of Hemlo Fault). Retrograded porphyroblasts (andalusite?) seen in some turbidites, are aligned on horizontal surfaces, parallel to S_3. Small–scale F_3 folds, with dextral offset along the axial plane which is commonly occupied by a quartz vein, are ubiquitous but not abundant. A relatively large–scale F_3 fold with an amplitude in the order of 50 m has been inferred from abrupt and significant changes in S_1 and S_2 orientations. F_3 folds of such size are rare but have been observed elsewhere in their entirety because of stripping (J. Grant, geologist, Esso Minerals Canada, Limited, Toronto, personal communication, 1988).

THE AREA OF THE NORTH ZONE, GOLDEN SCEPTRE PROPERTY

GENERAL GEOLOGY

The North Zone, exposed in trenches by Noranda Exploration Limited, is defined by erratic gold–molybdenum mineralization and lies within a fairly broad zone of irregularly developed alteration which also encompasses a South Zone: these two zones are essentially mineralized extensions of the Hemlo Deposit orebodies which lie to the east.

The area of the North Zone (Figure 34.2) is actually contiguous with part of the south boundary of the previously described terrain, and, as such, the rocks north of this area are volcaniclastic turbidites (metasandstone, metasiltstone). Structurally above, and within, the North Zone, the rocks are largely interpreted to be feldspathic volcaniclastic metaconglomerates, and coarse volcaniclastic sandstones, with minor feldspathic metasiltstone, and, locally, amphibole–rich (calc–silicate) layers. The matrix is biotite– and/or hornblende–bearing and is intermediate in composition. Clast types are virtually bimodal: feldspathic or biotite–rich. Relatively coarse–grained feldspar, and sparse quartz grains, interpreted to have originally been phenocrysts, are present but uncommon. The southern parts of some trenches contain felsic, quartz–feldspar porphyry of uncertain origin (extrusive or intrusive). Within the trenches is a relative abundance of dark grey, locally feldspar–porphyritic(?), mafic–xenolith–bearing, foliated, biotite "diorite" dikes.

Alteration

Alteration associated with the Hemlo Deposit takes the form of any combination of feldspathization, biotitization, carbonatization, silicification, and tourmalinization. In the North Zone, alteration appears mainly to have been a pervasive, moderate feldspathization and biotitization, followed by an intense feldspathization which was, in part, fracture–controlled, but has locally become so extensive as to become pervasive. In the latter case, the mafic minerals have been bleached, and quartz 'eyes' are generally destroyed: fragments may not be discernible. The origin of the rock is virtually impossible to acertain. The "diorite" dikes mentioned above have been partly feldspathized, particularly along fracture sets. Pyritized rocks, generally in shear zones, are locally present within the non–dike rocks.

STRUCTURAL GEOLOGY

The essential structural characteristics present in the terrain north and northwest of the Page–Williams Property are the same here. This area appears to lie within the south limb of the major F_2 fold first outlined on the Page–Williams Property. The S_1/S_2 intersection lineations plunge moderately to the northwest, as do mineral lineations (commonly tourmaline and amphibole), and clast elongations: all are sympathetic to F_2 fold axes. Slickensides on cleavage faces plunge shallowly to the west or east. Some surfaces show both lineations.

The intense feldspathization, as mentioned in the section on General Geology, is fracture and foliation controlled. Sets of alteration veins are commonly locally developed in outcrops, rather than appearing as continuous, widespread features (Photo 34.3). The alteration veins collectively appear to parallel S_1, S_2, and/or S_3 cleavages, as suggested by equivocal relationships, although not all cleavages are necessarily present or classifiable in any given outcrop. In addition, orientations from place to place do vary and, as such, a correlation of equivalent fabrics or structures from one place to another is difficult. Overall, sets tend to strike at least 10° apart (commonly 20°), and range from about 240° to 300°. Most commonly, strikes of sets are close to 260° and 280°, with a general preferred dimensional orientation of biotite, and flattening of clasts, at 270°. Locally, alteration veins in the country rocks and dikes are deformed into F_3 folds. A more detailed study of fabric and fracture orientations will be undertaken.

THE "C300" ZONE, PAGE–WILLIAMS PROPERTY

GENERAL GEOLOGY

Part of the "C300" Zone (Figure 34.2), was well stripped and hosed by some Page–Williams Mine staff. The opportunity was taken to map the outcrop area in detail (Figure 34.3). The essential host rock in this zone is presently a felsic, altered, quartz–feldspar–porphyritic mass composed of a number of incompletely distinguishable units. Heterolitic fragments are locally numerous (Photo 34.4), range from 4 to 40 mm long, and are moderately well

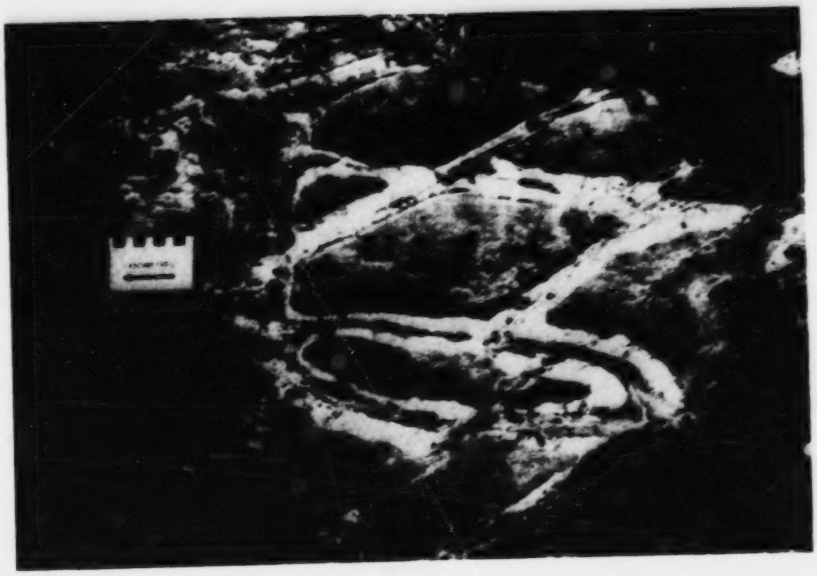

Photo 34.3. *Intense feldspathization along sets of fractures to produce a diamond-shaped or parallelogram pattern. Locally, the feldspathization has spread and eliminated any remnant material between the original fractures.*

sorted in size. They were observed at various locations as shown in Figure 34.3. The author interprets the fragment-bearing units to have been pyroclastic in origin. fragment-absent rocks are equivalent in origin. The possibilities for their origin include: a) felsic flows; b) hypabyssal intrusions; c) tuff and crystal tuff; or d) pyroclastic rocks with fragments destroyed during locally intense alteration. Within almost any 5 by 5 m area of this outcrop, green, vanadian muscovite (Harris 1986) lenses can be found. Most of these lenses also appear to be fragments.

Alteration

The host rocks have been variably altered. Several "zones", outlined on the map (Figure 34.3) according to a generalized field identification of the type of alteration, are as follows: sericitic, quartz–feldspar porphyry (QFP); feldspathized and biotitized QFP; feldspathized QFP; and variably pyritized QFP with irregularly shaped, chlorite–sericite "lenses" and disrupted "layers". The latter zone bears a superficial resemblance to some sort of fragmental rock, but may reflect a form of incipient alteration with subsequent tectonic disruption.

A later stage involving intense feldspathic alteration has produced west–northwest–trending 'veins' along some fractures in the host rock. Elsewhere, intense east-trending, feldspathic alteration, with attendant pyritization and various degrees of molybdenum and gold(?) mineralization, has occurred. In both cases, the alteration has destroyed virtually all of the quartz and feldspar phenocrysts. Pyritization has introduced fine-grained disseminated pyrite in all QFP types. However, it does not appear to be ubiquitous. Locally schistose (sheared?) zones weather with considerable oxidation of pyrite. Elsewhere, rusty weathering can be seen in places to be related to surfaces which were originally covered by lichen, moss, or thin soil, and, as such, is not a reliable indicator of the presence or absence of pyrite in the non-oxidized rocks. Silicification is locally evident in dike-like, fracture/shear-controlled(?) zones (Figure 34.3). These zones appear to consist largely of silica with intergranular fine-grained feldspar. They are distinct from the numerous quartz stringers and bull quartz veins which have various orientations and have formed at various times during the structural history. The thin, quartz stringers are locally numerous and are more or less parallel to the main fabric which generally strikes at about 275°. They appear to be most abundant in the poorly defined zone that contains the molybdenum–gold(?) mineralization, and have locally been subjected to at least the F_3 stage of deformation.

There are 13 dikes in this outcrop area, all of which are variably deformed, and are parallel or subparallel to the main fabric. Overall, the dikes range in composition from felsic, with quartz–feldspar and feldspar-phyric varieties, to intermediate and mafic varieties, some with biotite and plagioclase phenocrysts. The mafic dikes are generally variably sheared: kinematic indicators ("c–c′" fabrics) give a dextral sense.

STRUCTURAL GEOLOGY

This outcrop is in the central zone of deformation and alteration, and preserves a microcosm of the regional deformation history. It is not possible without

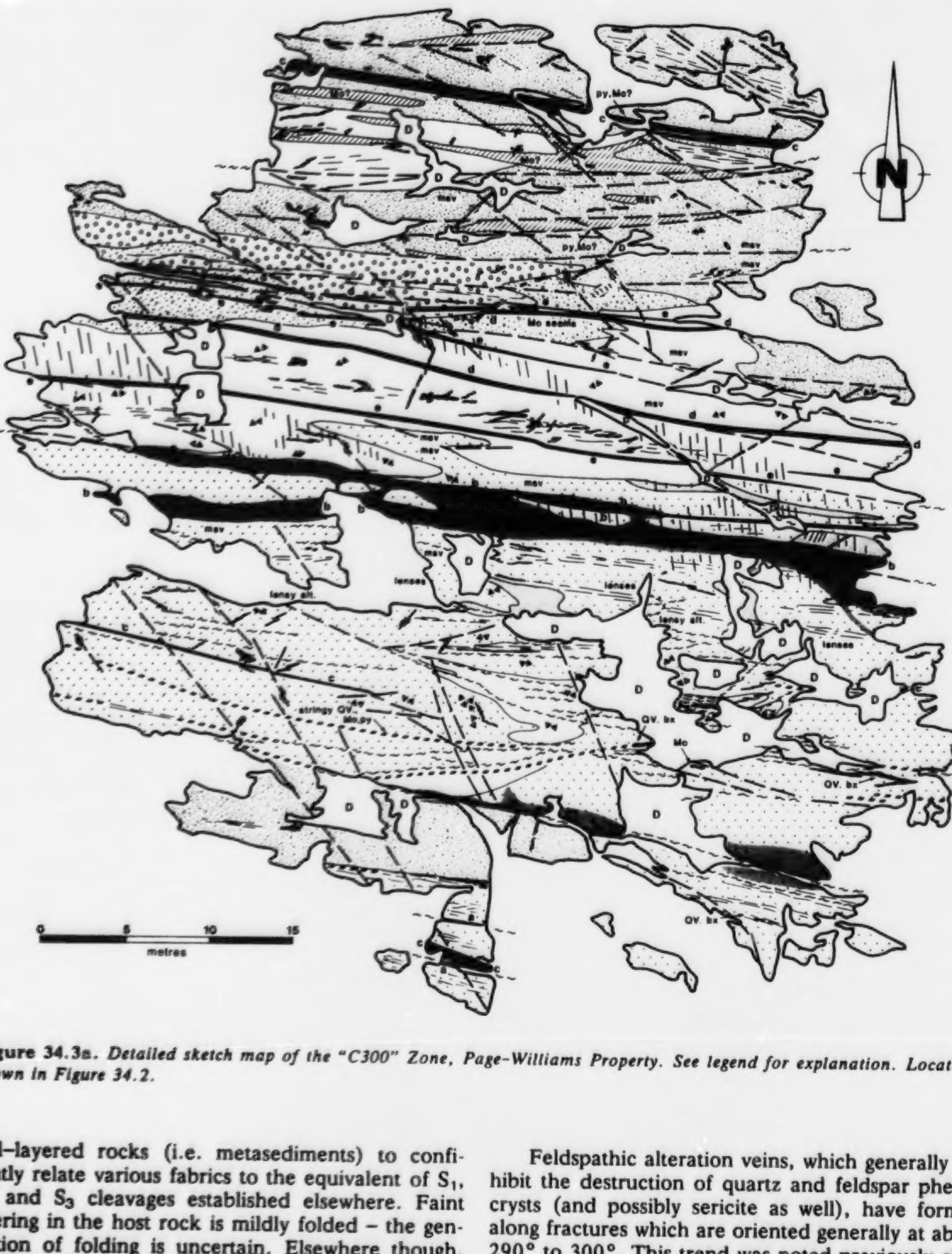

Figure 34.3a. *Detailed sketch map of the "C300" Zone, Page–Williams Property. See legend for explanation. Location shown in Figure 34.2.*

well–layered rocks (i.e. metasediments) to confidently relate various fabrics to the equivalent of S_1, S_2, and S_3 cleavages established elsewhere. Faint layering in the host rock is mildly folded – the generation of folding is uncertain. Elsewhere though, F_2–like folds have been noted in this rock type. The predominant fabric is either S_2, or the "c" fabric of an "s–c" dextral shear system, or possibly both, as evidence elsewhere suggests the fabrics may be largely co–planar. Sericite in seams usually displays the S_3 fabric best oriented counterclockwise to the seam. This may be the "s" fabric of an "s–c" system.

Feldspathic alteration veins, which generally exhibit the destruction of quartz and feldspar phenocrysts (and possibly sericite as well), have formed along fractures which are oriented generally at about 290° to 300°. This trend was noted previously elsewhere (Muir 1986) in the "C100" Zone, and in the North Zone (this report). It is also parallel to many dextral faults, in the outcrop area, which are of a brittle–ductile character.

Unequivocal examples of "s–c" fabrics indicative of subhorizontal dextral shear were observed only in the roughly east–trending mafic dikes and in

Quartz veins

INTRUSIVE CONTACT

Dikes

- e Biotite-plagioclase-porphyritic, biotite diorite (sheared)

INTRUSIVE CONTACT

- a Biotite gabbro (sheared)
- b Biotite quartz diorite
- c Feldspar porphyry
- d Quartz-feldspar porphyry

INTRUSIVE CONTACT

Country Rock

- ░ Sericitic, quartz-feldspar porphyry
- ☐ Feldspathized, biotitized, quartz-feldspar porphyry
- ░ Feldspathized quartz-feldspar porphyry
- ░ Quartz-feldspar porphyry with irregularly shaped chlorite-sericite lenses, layers
- ░ Pyritized quartz-feldspar porphyry with irregularly shaped chlorite-sericite lenses, layers
- ☐ Intensely feldspathized rock with py-Mo-Au(?) mineralization
- ▨ Zone of notable pyritization, Au(?)
- Intensely silicified rock (dike-like)
- Quartz stringers, veinlets
- Quartz veins
- ■ pink (hematitic) alteration
- conspicuous fracture/shear, with or without alteration
- alteration "vein" along fracture
- area of fragment-bearing rocks
- closely spaced fracture sets
- highly schistose zones
- D dirt

Figure 34.3b. *Legend.*

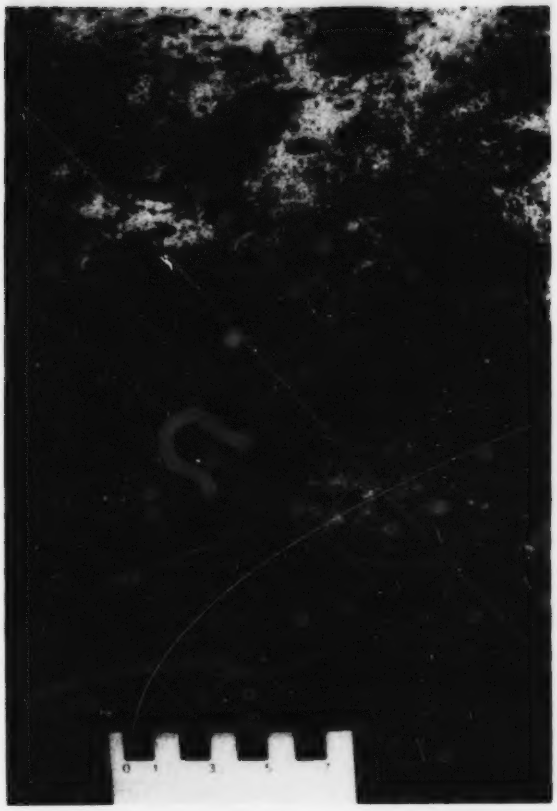

Photo 34.4. *Feldspathized, quartz-feldspar porphyry with numerous, flattened, somewhat heterolithic, lapilli-sized fragments, suggesting a pyroclastic origin. The unit is weakly pyritized. The main zone of mineralization in the "C300" Zone lies about 10 m to the north (towards top of photo).*

some northwest-trending shears. A few of the dikes exhibit a "c′" fabric. In most other cases, particularly in the sericitic quartz-feldspar porphyry, generally east-trending fabrics take on more of an anastomosing appearance around phenocrysts with no clear asymmetric or sigmoidal relationships. Locally, two sets of cleavages, spaced from about one to several millimetres apart, have produced a diamond pattern which may give an appearance somewhat akin to that of an "s-c" fabric pair. However, close inspection reveals an equivocal relationship with no sense of simple shear. The diamond pattern was noted with cleavage pairs at about 275° and 305°, and 275° and 235°. In both cases it appears that the 275°-trending set has been overprinted by the second set.

The configuration and deformation of various quartz veins indicates there were several episodes of vein emplacement. A set of highly deformed veins lies within feldspathized/biotitized quartz-feldspar porphyry, structurally above the main zone of mineralization. North-northeast to east-northeast-trending quartz veins post-date the highly deformed veins: some are associated with dextral movement along their length. Others have been dextrally offset at several locations across their length. Some northeast-trending veins have a dilational (gash-like) fracture appearance, with an S-shaped configuration. A few veins strike almost due north.

The predominant fracture/fault set of significant scale in this outcrop is northwest-trending, and, where determinable, has a dextral sense with a small resultant horizontal offset (less than 0.5 m) relative to markers (e.g. dikes, compositional layering). A much weaker, northeast-trending fracture/fault set, where determinable, shows sinistral offset of fabrics and/or compositional markers. Closely spaced fracture sets trending from 350° to 360° have formed locally along northwest-trending dextral shear zones. Coupled with a spaced cleavage trending in a roughly easterly direction, these sets produce an almost shattered appearance in the rock, except that the fractures are regularly oriented. Other, possibly later, conjugate fracture sets with north–northwest and north–northeast trends have minor, dextral and sinistral offsets respectively.

Using the results of experimental shear, reported by Skempton (1966) and Ramsay and Huber (1987), a cursory examination of orientation and sense of shear suggests that the northwest-trending feldspathic veins/fractures/shears may be equivalent to "R" shears, and the closely spaced 'shatter' fractures may be equivalent to "R′" shears. However, such a designation does not provide a ready explanation for the orientation of quartz veins, many dextral and sinistral shears, and, most importantly, the dextral brittle–ductile faults associated with small-scale F_3 folds. The simplistic assumptions required to draw the above analogy will require closer scrutiny and may be invalid, given the polyphase deformation history of the area.

DISCUSSION

This section considers a number of items or challenges that have become evident this field season or have been modified or clarified from previous seasons. Most of them involve metamorphism (i.e. regional), hydrothermal alteration (i.e. deposit scale), deformation, and their timing or relative geochronology.

1. The determination of top directions is possible in few units. So far, almost all field interpretations are based on grading, with an assumption that normal processes were operative. Coarse clastic rocks pose little problem where they are relatively undeformed. However, problems were noted with meta-arenites and metasiltstones. Because of the mid-amphibolite-facies metamorphism in the map area, metamorphic recrystallization and resultant grain-size reversals must be taken into account. Commonly, the beige to grey-brown, quartzo- feldspathic parts of turbidites have remained finer grained than the presently coarser-grained and darker-coloured, biotite- and/or amphibole-bearing parts. It was noted in some cases that presently coarser-grained parts of units, containing feldspar and quartz crystals as well as biotite/amphibole, form the bottom of a bed which has a lighter coloured, fine-grained top. Elsewhere, reasonably good control for top determinations was possible, and it was observed that coarser-grained feldspar, along with biotite/amphibole, defines the upper part of some units, suggesting that the feldspar is metamorphic. If this is so, it serves only to further reduce the reliability of top determinations in arenaceous rocks, which, by far, account for the majority of rocks in this area.
2. Evidence continues to corroborate the observations and conclusions obtained previously (Muir 1986; Muir and Elliott 1987) that the majority of the area is structurally underlain by medium- and small-scale, S-shaped, F_2 folds. This suggests that the F_2 generation of folds was formed during a period of sinistral shear. One cannot, without detailed mapping of a significantly larger, regional-size area, distinguish between a case where a relatively small area, such as the present map area, is underlain by a long limb of a regional S fold (overall sinistral sense), or the short limb of a Z fold (overall dextral sense). Both cases would produce S-shaped parasitic folds during regional folding. It is of interest though, that a large-scale S fold was outlined by Muir (1982) along the west side of Mussy Lake, about 16 km to the southwest of the Hemlo Deposit. The author thinks that this supports a regional sinistral event for the F_2 folds.
3. Evidence for dextral shear (Hugon 1984, 1986; Hugon and Schwerdtner 1988), such as "s–c–c′" fabrics, that resulted, in part, in the formation of F_3 Z-folds, is incontrovertible. However, the extent to which dextral shearing has produced real or so-called mylonites, schists, intense flattening of clasts or folds, and dimensional elongation of clasts can be questioned.

One problem relates to the recognition of "s–c" fabrics. Although "s–c" fabrics may be considered to be specific cases of a crenulation cleavage relationship that is formed during progressive deformation, they must be distinguished from: a) weak to mild development of crenulation of an older fabric by a younger one, in the traditional sense; b) partly similar-looking relationships which may be produced by two distinct ages of flattening fabrics to form a "deflector" fabric paired with a "deflectee" fabric, as suggested by fabric relationships in the Temagami greenstone belt (e.g. J.A. Fyon *et al.*, this volume); or c) closely spaced cleavage sets which, when further deformed, particularly if phenocrysts or small clasts are present, produce a real or apparent anastomosing pattern essentially during pure shear as suggested by fabric relationships in the Wawa greenstone belt (e.g. Heather and Buck, this volume). Taking these possibilities into account, there are few rocks in the map area which display unequivocal "s–c" fabrics by field identification.

Another problem relates to the recognition of stretching lineations produced in an essentially simple shear system, and dimensional elongation lineations produced during regional folding (buckling) where clast (and other primary feature) elongation, some mineral lineations, and layering/axial planar cleavage intersection lineations all parallel the fold axes, as seems to be the case for this map area. Slickensides and crinkle lineations in the map area are generally subhorizontal and are roughly orthogonal to "s–c" intersections. They are also almost orthogonal to the dimensional elongations discussed above. Unequivocal stretching lineations appear to be rare in the map area (cf. Hugon 1984; Hugon and Schwerdtner 1988).

4. The establishment of the timing of events relative to the formation of the deposit is important and continues to be somewhat elusive. Muir and Elliott (1987) reported retrograded porphyroblasts (andalusite?) in metasediments in the vicinity of the deposit, which were aligned in the S_3 foliation plane and crudely lineated parallel to F_3 axes. Similar porphyroblasts were observed this season well away from the deposit and any of its recognizable related hydrothermal alteration (*see* section on Terrain North and Northwest of the Page–Williams Property). This prompts the author to suggest that regional metamorphism may have coincided with the dextral shear event.

The problem of the timing of alteration and mineralization relative to regional folding, diking, and dextral shearing remains. A vast array of rock types in this tightly folded terrain, as seen in large trenches on the Golden Sceptre Property, have been altered. This includes at least some dikes which appear to be parallel to the S_2 cleavage and hence have likely used the existing fabric weakness during intrusion. Other dikes, not displaying obvious alteration effects, are considerably less deformed and pyritized than the country rock. Rheological differences aside, the dikes appear to be post–mineralization. Of the ore zone dikes sampled for U–Pb geochronology (Corfu and Muir 1988) all have what are interpreted to be muscovite poikiloblasts. Although this suggests that their intrusion may have preceded deposit alteration, this is not clear by their overall appearance. There is still the possibility that the poikiloblasts actually formed during a regional metamorphic event in which these unaltered dikes were lying within an already altered, mineralized, potassic–rich environment. Fluids circulating during the metamorphism would have been responsible for the incipient potassic alteration of the dikes (i.e. poikiloblast development).

In summary, then, it is possible that alteration was pre–, or syn–, early dextral shear. A complicating factor, as reported last year (Muir and Elliott 1987), is that the main plunge of the orebody is roughly parallel to the F_2 folds in the vicinity, based on published vertical projection longitudinal sections of the orebody. However, these sections are based on early "ore grade" delineations from exploration diamond drilling intersections. There is a real or apparent secondary lineation of the orebody to the northeast, roughly–parallel to F_3. As of now, information is lacking regarding whether the David Bell West Zone is linked to the East Zone by sub–ore grade mineralization, and whether the Page–Williams Property "Heritage" outcrop mineralized zone is linked to the "B" Zone, and, if so what configuration would result.

There is no unequivocal or even reasonably reliable evidence to show the orebody is folded about an F_2 fold. The author has not observed any F_2 (west–plunging) folds in the orebody underground. All folds observed were east–plunging "Z" folds which appeared to be F_3 folds. Therefore, if the deposit formed prior to the F_3 gold generation, the movement of fluids was at least partly controlled by an axial–planar shear zone set up after most F_2 folding had taken place. If such was the case, the alteration mineralization would have taken place during a sinistral shear event. Such evidence is lacking in the ore, although it may have been destroyed during the dextral shear event. Alternatively, if the fluids passed through the rocks after F_2 folding, but before F_3 folding, they would have to have been largely controlled by existing fabrics in order to explain the orebody plunge; but they would not necessarily incorporate evidence of sinistral shear.

Another alternative explanation would have deposit–related fluids contemporaneous with early dextral shear (F_3). Evidence seemingly in support of this is locally found on the extremities of the alteration/shear zone where the later, intense feldspathization as 'veins' is structurally controlled and locally related to fractures and dextral shear planes. However, these 'veins' overprint an earlier alteration which appears to involve feldspathization and biotitization as well as the introduction of gold and/or molybdenum (Muir *et al.* (1988), and were themselves locally deformed during the F_2 event. Some specimens from the ore zone alteration system reveal that a fine–grained, microclinized, quartz–feldspar porphyritic rock had later been altered to a very fine–grained, quartz–feldsparmicrocline–sericite rock along zones which are essentially anastomosing, and have resulted in a pseudo–fragmental–looking rock. Therefore, there are several stages of alteration, but principal episodes and hiatuses have not been defined.

Previously, various authors, subject to specific qualifications, favoured mineralization and related alteration to have: a) predated much deformation and regional metamorphic recrystallization (Burke *et al.* (1986); Kuhns *et al.* (1986); or b) been synchronous with tectonism, and post–peak metamorphism (Hugon 1986; Walford, Stephens, Skrecky, and Barnett (1986b)).

The above points serve to caution readers about using selected points of observation/interpretation without considering them as part of the whole. The "whole" is still, in the author's opinion, clearly supportive of an epigenetic deposit, but not yet precisely defined in terms of the various geological components.

ACKNOWLEDGMENTS

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Wawa Area

35. Project Number 87–14. Geology of the Kabenung Lake Area, District of Algoma

R.P. Sage

Geologist, Precambrian Geology Section, Ontario Geological Survey, Toronto.

INTRODUCTION

A comprehensive program of detailed bedrock mapping in the Michipicoten Greenstone Belt has been carried on by the Ontario Geological Survey (OGS) since 1976. To date, 15.3 townships have been mapped at a scale of 1:15 840 or 1 inch to 1/4 mile, covering a surface area of 1410 km^2 (551 miles^2). In 1988, mapping was carried out by the author in the Kabenung Lake area (*see* Figure 35.1) to complete a project begun in 1987 (Sage 1987) to map Killins, Knicely, and Lalibert townships. Mapping was also conducted in the Iron Lake area, immediately to the west (Reilly, this volume).

The major objectives of this program have been to outline lithological distribution, unravel the supracrustal stratigraphy, and outline major regional structures. Because facing data, which are critical to attaining these goals, are most likely to be found on lakeshore exposures, some emphasis was placed on the mapping of lakeshore geology.

This program of geological mapping has provided an extensive data base for other, more focused studies in the Michipicoten belt by OGS personnel. Detailed structural studies were begun in the Goudreau–Lochalsh area, now the focus of extensive exploration for gold, in 1987 (Arias and Heather 1987; Heather and Arias 1987). In 1988, these programs continued, with studies in the Renabie area (Heather and Buck, this volume), and the start of a regional structural analysis (Arias, Queen's University).

Other OGS programs are also adding to the data base. The results of an airborne electromagnetic and magnetic survey were released in 1988 (Barlow, this volume). As well, the supracrustal belt has been flown for radar imagery under the direction of the Ontario Centre for Remote Sensing, and this data is being used in a test study (Trowell and Mussakowski, this volume). Geochemical studies were begun in 1987 and continued in 1988 (Fortescue, this volume). The geochemical studies provide an excellent data base for future mineral exploration programs in the Wawa region.

University–based research programs active in 1988 include a structural study in the area of Chabanal Township by personnel from the University of Massachusetts (McGill and Shrady 1986), and a continuing program of geochronological studies by A. Turek *et al.* (1982, 1984, 1988) of the University of Windsor. In addition, R. Thorpe (1987), of the Geological Survey of Canada, is continuing investigations of the Pb–Pb isotopic systems in the Wawa area.

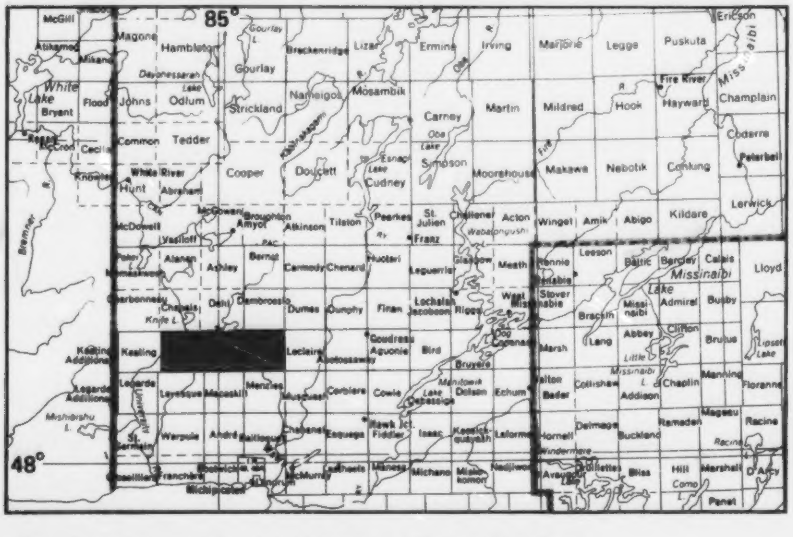
85°
48°
McGill
Magone
Hambleton
Gourlay
Breckenridge
Lizar
Ermine
Irving
Marjorie
Legge
Puskuta
Ericson
White Lake
Flood
Johns
Odlum
Strickland
Nameigos
Mosambik
Carney
Martin
Mildred
Hook
Hayward
Champlain
Common
Tedder
Cooper
Doucett
Cudney
Simpson
Moorehouse
Makawa
Nebotik
Conking
Peterbell
Hunt
White River
Abraham
McGowan
Broughton
Amyot
Atkinson
Tilston
Peerless
St. Julien
Acton
Wingel
Amik
Abigo
Kildare
Lerwick
McDowell
Vasiloff
Alanen
Ashley
Bernst
Carmody
Chenard
Hucitari
Leguerrier
Glasgow
Meath
Rennie
Leeson
Baltic
Barclay
Cabis
Lloyd
Missinaibi
Dahl
Dambrossio
Dumas
Dunphy
Finan
Lochalsh
Jacobson
Riggs
Stover
Bracken
Admiral
Busby
Knife L.
Keating
Leclair
Goudreau
Aguonie
Bird
Marsh
Lang
Abbey
Clifton
Brutus
Bruyere
Lodorde
Levesque
Menzies
Musquash
Corbiere
Cowie
Dolson
Echum
Collishaw
Chaplin
Manning
Floranna
Bader
Addison
Warpula
Andre
Chabanal
Esquega
Fiddler
Isaac
Kesick
Lalibert
Hornell
Delmage
Buckland
Ramsden
Racine
St. Germain
Franchere
McMurray
Michipicoten
Chicaman
Nedin
Avery
Gillette
Bliss
Hill
Marshall
D'Arcy
Como
Panet
Whitman
Magney

Figure 35.1. *Location of study area. Scale 1:1 584 000 or 1 inch to 25 miles.*

Access to large areas of Killins, Knicely, and Lalibert townships is via extensive lake and river systems or logging skid roads. The northwestern corner of Killins Township, the southwestern corner of Lalibert Township, and the southeastern corner of Knicely Township are easily accessible by helicopter.

MINERAL EXPLORATION

The area was extensively explored for iron around the turn of the century, with isolated limited activity as late as 1966. The Francis–Brotherton, Brant Lake, Betty Lake, and Morse Mountain iron ranges have all been extensively prospected, unsuccessfully, for iron.

Killins, Knicely, and Lalibert townships have been subjected to a number of regional exploration programs, principally for base metals. The first regional program was that of Acme Gas and Oil Company Limited, in 1969. In 1971, Union Miniere Explorations and Mining Corporation Limited completed an extensive program of ground investigation of airborne–indicated electromagnetic and magnetic anomalies throughout the region. In 1980, Amax Minerals Exploration Limited examined existing data from previous programs and re–investigated a number of geophysically anomalous areas.

The only base metal deposit of significance within the map area is the Heart Lake copper occurrence. In 1962, this showing was drill–tested by Falconbridge Nickel Mines Limited, Jon Smith Mines Limited, and Dickenson Mines Limited.

The entire map area is currently under the control of International Corona Resources Limited, which has completed airborne electromagnetic and magnetic surveys, ground investigations, and limited diamond drilling in search of gold and base metals.

GENERAL GEOLOGY

METAVOLCANIC ROCKS

The general geology of the area is complex (Figure 35.2). Intermediate to mafic massive to pillowed volcanics are widespread in distribution. Intermediate to mafic tuffs and breccias are not common, being only of local distribution and occurring between the much more common flow rocks. Massive to pillowed intermediate to mafic volcanics occur in the northern and southern portions of Lalibert Township, in southern Knicely Township, and in the southern and northwestern portions of Killins Township (Figure 35.2). Amygdules may be common in the intermediate to mafic metavolcanics in some areas, and vary up to a maximum size of 10 mm. On the basis of amygdule size, the flows were rich in gas or extruded into a low pressure (shallow water) environment.

Intermediate to felsic metavolcanics are also widespread. They consist of coarse oligomictic to polymictic breccias, lapilli tuffs, quartz–feldspar crystal tuffs, feldspar crystal tuffs, and massive to bedded tuffs. The most extensive area of intermediate to felsic metavolcanics extends to the southwest away from the margin of the Dickenson Lake Stock, in southern Lalibert Township (Figure 35.2), and is indicated as sediment on older compilation maps (Milne *et al.* 1971). Only volumetrically minor, thin units of argillite, siltstone and wacke occur within these intermediate to felsic metavolcanics.

Within the coarse fragmental volcanics, the matrix is commonly much more mafic than the clasts. These felsic clast mafic matrix breccias are very common within the southeast–striking band of intermediate to felsic metavolcanics in Lalibert Township.

A large area of massive bedded intermediate to felsic tuff occurs northwest of Dickenson Lake in Knicely Township. These felsic metavolcanics are enclosed within the fold structure outlined by the Betty Lake and Elmo Lake iron ranges.

Along the south flank of the Jimmy Kash Lake Iron Range, a relatively continuous band of intermediate to felsic breccias, tuffs, and quartz–feldspar crystal tuffs is present. These intermediate to felsic metavolcanics extend from south–central Knicely Township to near the western boundary of Killins Township.

A thick sequence of quartz–feldspar crystal tuff occurs on the west side of the iron formation at the Morse Mountain Iron Range.

Massive to bedded fine–grained tuffs and crystal tuffs occur west of the University River in Killins Township. A laminated chert horizon locally separates these intermediate to felsic metavolcanics from clastic metasediments to the south.

CLASTIC METASEDIMENTS

Clastic metasediments form a major lithological package in central Lalibert Township, and occur near Paint and Kabenung lakes and along the northern edge of Knicely Township. They form a wide band through the central portion of Knicely Township, and are common in the northeastern part of that township (Figure 35.2).

The metasediments in Lalibert Township consist of a south– facing sequence of massive to thin–bedded argillite, siltstone, wacke, and subarkose. The metasediments along Paint and Kabenung lakes in Killins and Knicely Townships are wacke, siltstone, and conglomerates. The conglomerates on Paint Lake and those on the northern border of Killins Township on Kabenung Lake contain rare granitic clasts and are Dore–type conglomerates (Collins and Quirke 1926). The metasediments in central Killins Township consist of wacke and siltstone, north and south of a central band of Dore–type conglomerate. In northern Killins Township, a thick conglomerate unit contains few, if any, granitic clasts, but does lie

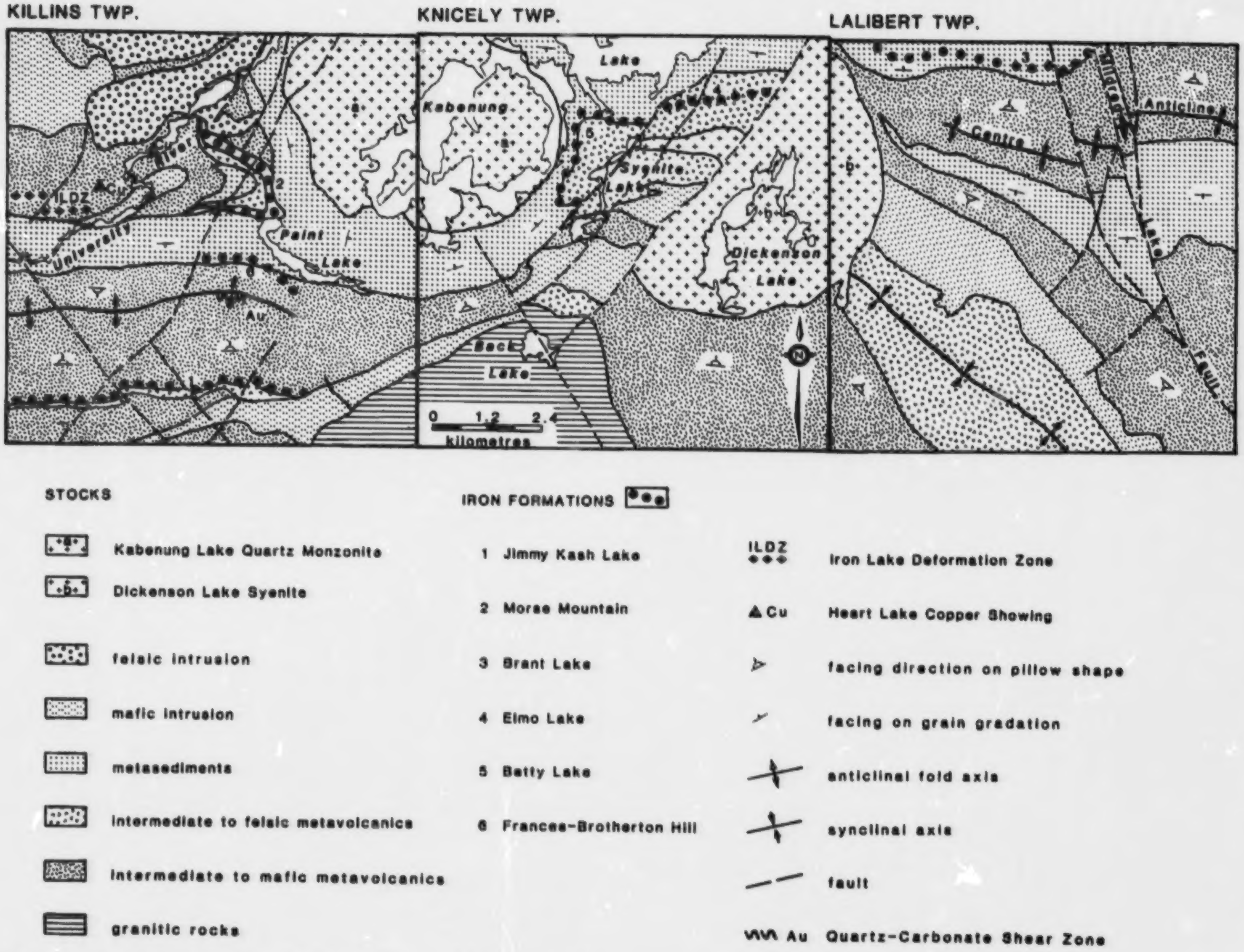
KILLINS TWP.
KNICELY TWP.
LALIBERT TWP.
Kabenung
Lake
Syenite
Lake
Dickenson
Lake
Paint
Lake
University
Back
Lake
Centre
Mildred
Anticline
Lake
Fault
ILDZ
Cu
Au
0
1.2
2.4
kilometres
N
STOCKS
Kabenung Lake Quartz Monzonite
Dickenson Lake Syenite
felsic intrusion
mafic intrusion
metasediments
intermediate to felsic metavolcanics
intermediate to mafic metavolcanics
granitic rocks
IRON FORMATIONS
1 Jimmy Kash Lake
2 Morse Mountain
3 Brant Lake
4 Elmo Lake
5 Betty Lake
6 Frances-Brotherton Hill
ILDZ Iron Lake Deformation Zone
Cu Heart Lake Copper Showing
facing direction on pillow shape
facing on grain gradation
anticlinal fold axis
synclinal axis
fault
Au Quartz-Carbonate Shear Zone

Figure 35.2. *Generalized geological map of Knicely, Killins, and Lalibert townships.*

on strike with conglomerates that do contain granitic clasts further east in Knicely Township.

Graded bedding is common in the wackes and is the principal feature for determining stratigraphic facing directions in the map area.

CHEMICAL METASEDIMENTS

Iron formation ranges are abundant in the map area. These are known as the Morse Mountain (or Mount Raymond), Jimmy Kash Lake, Brant Lake, Elmo Lake, Betty Lake and Francis–Brotherton iron ranges (Figure 35.2). They commonly crop out as ridges, and consist dominantly of banded to laminated chert. Magnetite and iron sulphide are common accessory minerals. The iron ranges form the best geological and geophysical markers within the supracrustal rocks.

INTRUSIVE ROCKS

Felsic intrusive rocks are common within the project area. They are dominated by the Kabenung Lake monzonite to quartz monzonite stock and the Dickenson Lake syenite stock (Figure 35.2).

In central Knicely Township, a small syenite to granodiorite body occurs between Syenite and Dickenson lakes. In north– central Killins Township, a small granitic body occurs east and west of the University River. Northwest of the University River, massive porphyritic and nonporphyritic granodiorite bodies occur that are enclosed within supracrustal rocks. These supracrustal rocks range in metamorphic grade from upper greenschist to lower amphibolite.

Kabenung Lake Stock

The Kabenung Lake Stock consists of massive medium– to coarse–grained inequigranular seriate porphyritic monzonite to quartz monzonite. The quartz content varies widely between outcrops. High hills and ridges in central Killins and Knicely townships are underlain by rocks of this stock, which is enclosed within a contact metamorphic aureole 0.5 to 1.0 km wide.

Dickenson Lake Stock

The Dickenson Lake Stock consists of medium– to coarse–grained equigranular massive grey syenite. Only locally can trace amounts of quartz be found. A large block of medium– to coarse–grained gabbro occurs within the central portion of the stock, and may be a roof pendant completely enclosed within the intruding syenite magma. The eastern side of the Dickenson Lake Stock has a contact metamorphic aureole 1.0 km or more in width. The western side is in fault contact with the supracrustal rocks and a recognizable aureole is not apparent.

Mafic Intrusive Rocks

Intermediate to mafic intrusive rock is common throughout the supracrustal package, and. locally composes more than 50 percent of the stratigraphic section (Figure 35.2). The intermediate to mafic intrusions appear sill–like locally, but regionally some display crosscutting relationships. The intrusions vary from fine to coarse grained and commonly are difficult to distinguish from the metavolcanic rocks.

In central Killins Township, a gabbroic anorthosite to anorthositic gabbro body was outlined. This unit consists of 80 to 90 percent plagioclase, in crystals up to 2 cm in size. The body is sill–like in outline, but the occurrence of dike–like bodies of similar rock cutting the enclosing metavolcanics establishes its intrusive nature.

Diabase Dikes

Diabase dikes are abundant in the map area, and represent northwest– and northeast–trending sets. The dikes appear to be a conjugate set and typically display alteration to a greenschist grade of regional metamorphism. The dikes pinch and swell along strike, can be composite in nature, and can vary from porphyritic to nonporphyritic along strike. The metamorphosed nature of most of the dikes makes them difficult to distinguish from other mafic intrusive rocks in the field conditions encountered, and suggests that most are probably Archean in age. The rather consistent strike of most suggests that only minor deformation has occurred since Archean time.

A magnetic northeast–trending diabase dike 100 m wide cuts across Lalibert Township. This dike is very fresh in appearance and is likely Proterozoic in age.

STRUCTURAL GEOLOGY

FOLDING

The regional Centre Anticline (Sage 1987) extends from Leclaire Township into Lalibert Township (Figure 35.2). The position of the fold axis is uncertain, but lies north of the south–facing metasedimentary band that strikes northwest across Lalibert Township. The fold axis terminates east of the Dickenson Lake Stock, where the north limb of the fold is sheared out and highly attenuated. The Centre Anticline is an east–plunging synformal anticline.

A regional synclinal axis occurs within the intermediate to felsic metavolcanics that strike northwest across the southern half of Lalibert Township (Figure 35.2). The fold is defined by a south–facing section exposed along Highway 17, and a north–facing (based on pillow shape) section in southwestern Lalibert Township. The position of the fold axis is not precisely known due to the lack of facing data within the intermediate to felsic metavolcanics in which it lies. This fold is terminated in the west by the Dickenson Lake Stock.

A third regional fold occurs in the southern half of Killins Township (Figure 35.2). This fold is a syncline whose axis lies within metavolcanics and metasediments. Southeast of Paint Lake, the fold could not be traced east into Knicely Township but it can be extended west towards Iron Lake (Reilly, this volume). The syncline is defined by a north-facing volcanic section in southern Killins Township and a south-facing metavolcanic and metasedimentary section in central Killins Township.

A minor fold is outlined in the Syenite Lake area by the distribution of the Betty Lake and Elmo Lake iron ranges (Figure 35.2). It is open to the east and encloses a dominantly intermediate to felsic metavolcanic assemblage. In less deformed parts of the Michipicoten belt, intermediate to felsic metavolcanics occur at the stratigraphic base of the iron formations. If this observation holds for this area, this fold is an anticline.

A second minor fold occurs in central Killins Township, outlined by the Morse Mountain Iron Range (Figure 35.2). This fold opens to the west; from the observed position of the intermediate to felsic metavolcanic rocks with respect to the iron formation, it is an anticlinal structure.

The two minor folds may be related to the emplacement of the Kabenung Lake Stock.

FAULTING

Faulting is of two types, strike–slip and transverse. Lithological contacts are commonly sheared, implying that movement along contacts occurred during folding of the supracrustal rocks. The lack of marker horizons transverse to the stratigraphy prevents determining the relative amount of movement along these strike–slip faults. A pronounced zone of shearing and deformation in west-central Killins Township may be the eastern continuation of the Iron Lake Deformation Zone (ILDZ), recognized by Reilly (this volume) in the adjoining area. At least locally, this zone is conformable with stratigraphy. It may bend northward and join with shear zones along the Heart Lake University River system, where shearing is transverse to lithological trends.

In central Killins Township, a quartz–carbonate shear zone up to 40 feet in width was traced for 1000 feet. The zone displays alteration typical of some gold–bearing shear zones in the Wawa area. The lateral extent of the shear is unknown.

Evidence of deformation is common along the southern greenstone–granite contact. Trondhjemites and quartz diorites commonly are foliated and lineated, and display good cataclastic textures on weathered surfaces. Granodiorites may also display cataclastic textures, but deformation textures are poorly developed in these rocks. Some outcrops of granodiorite in the Back Lake area displayed little evidence of significant deformation. Large blocks of supracrustal rocks along the external granite–supracrustal contact, combined with the presence of deformation textures, suggests that granite intrusion preceded deformation.

Transverse faults are abundant in the map area and usually display left–lateral offset. Only the major transverse faults are discussed here. In central Lalibert Township, a major north– to northwest–striking diabase–filled fault offsets the metasedimentary rocks in a left–lateral manner. This fault is the northern extension of the Mildred Lake Fault (Sage 1980). A northwest–striking diabase–filled unnamed fault immediately east of the Dickenson Lake Stock truncates the metasedimentary band that strikes northwest across Lalibert Township.

The western side of the Dickenson Lake Stock is the site of a northeast–striking fault zone, which is represented by sheared fissile rocks, linear topographic features, brecciation of the stock, and hydrothermal alteration. A western faulted extension of the stock could not be found, perhaps suggesting that the fault predates the main phase of the intrusion, controlled syenite magma emplacement, and was later reactivated.

Left–lateral offset between the Betty Lake and Elmo Lake iron ranges suggests a north– to northwest–striking fault in central Knicely Township.

Most of the diabase dikes occupy shear or fault zones, even though offset may not always be readily apparent. The diabase– filled fault zones commonly are represented by one major dike, and there may be numerous narrower dikes subparallel to it. Some of these minor dikes may also occupy minor faults which offset the stratigraphy.

ECONOMIC GEOLOGY

The iron formations of the area are silica–rich, and contain only minor amounts of magnetite, pyrite, siderite, or hematite. Their iron content is too low to be of immediate or near future value, and prospecting for iron deposits of commercial value appears unwarranted. However, they are commonly folded, faulted, and fractured, and would thus make a good target for the gold prospector.

Shearing is abundant in the project area but rock alteration and silicification associated with shearing, which characterize gold deposits in the Wawa area, appear to be developed best in southwestern Knicely Township and in southern Killins Township. These shear zones occur in all lithologies and locally appear to follow lithological trends.

Except for the Heart Lake copper occurrence, base metal mineralization is largely unknown within the area. The Heart Lake showings occur in a linear pattern within sheared rocks, as disseminated grains and massive lenses in association with pyrite. The shearing may be related to the eastern extension of the Iron Lake Deformation Zone. One trenched showing of chalcopyrite was located this season on the southeastern corner of Heart Lake.

Bennett and Thurston (1977) described the Heart Lake occurrence as being in sheared mafic metavolcanics, close to the metavolcanic–metasedimentary contact. The showings described by Bennett and Thurston (1977) were not visited, but two detailed stratigraphic sections were completed starting 2 km west along strike from the main showings. From the stratigraphic bottom to top, the sections comprise intermediate to mafic tuffs and flows, intermediate to felsic tuffs and crystal tuffs, laminated chert, siltstone–argillite, and siltstone–wacke. The Iron Lake Deformation Zone lies within felsic and mafic metavolcanics just below the chert horizon. Fine-grained sugary quartz (recrystallized chert) is common in some of the Heart Lake copper samples examined by the author, and may be the lateral equivalent to the chert unit found in the stratigraphic section to the west. While the Heart Lake occurrences are in a zone conformable with stratigraphy, this mineralization is also closely associated with shearing. Alteration that could be analogous to an alteration pipe below a massive sulphide deposit was not encountered.

RECOMMENDATIONS TO PROSPECTORS

Shear zones with associated silicification, carbonatization, sulphidization, and potassic alteration should be examined for gold. The recognition of shear zones with silicification and carbonate alteration in southwestern Knicely Township and southern Killins Township suggests that this area may have gold potential. Evidence of potassic alteration (biotite or sericite) or the development of sulphide mineralization (pyrite or pyrrhotite) was not noted to be extensively developed in these shears, but this may be a function of the limited availability of outcrop. The quartz–carbonate shear zone found by the mapping party in south-central Killins Township is up to 40 feet wide and 1000 feet long, and open at both ends. It lies along or close to a regional synclinal axis, and may have a considerable extent along strike. Table 35.1 gives the gold content of grab samples collected along this shear. The values indicate subeconomic but geochemically anomalous gold contents. Intermediate to mafic rocks of the Wawa area generally have a background gold content of 1 to 3 ppb (Sage, unpublished data). Routine prospecting of this shear is warranted. There was no evidence of prospecting of the shear at the time of mapping.

TABLE 35.1: GOLD CONTENT OF GRAB SAMPLES FROM QUARTZ-CARBONATE SHEAR ZONE, KILLINS TOWNSHIP. DETERMINATIONS BY THE GEOSCIENCE LABORATORIES, ONTARIO GEOLOGICAL SURVEY, TORONTO.

Sample	Fire Assay	ppb Au
W739-56	<0.01	4
W739-61	<0.01	<2
W739-62	<0.01	<2
W739-63	0.01	110
W739-65	<0.01	21
W739-66	<0.01	<2
W73972A	<0.01	<2
W73972B	<0.01	<2

The Heart Lake copper occurrence needs reexamination. The close association of shearing with this copper mineralization is encouraging for gold mineralization. This mineralization occurs over a strike length of 2 km, indicating a lengthy zone for examination. Mapping and sampling east and west along the extrapolated extension of this zone are recommended.

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36. Project Number 88–09. Geology of the Iron Lake Area, District of Algoma

B.A. Reilly

Geologist, Precambrian Geology Section, Ontario Geological Survey, Toronto.

INTRODUCTION

The Iron Lake area, which is centred approximately 45 km northwest of Wawa, lies in the Michipicoten Greenstone Belt immediately north of the Mishibishu Lake area that is currently undergoing extensive exploration for gold. Keating Township, along with Keating Additional Township and the adjacent area extending 2 km to the south into Legarde Township and Legarde Additional Township, was mapped during the 1988 field season as part of an Ontario Geological Survey program to provide a comprehensive geological data base for the Michipicoten belt (*see* Sage, this volume).

The map area (Figure 36.1), which encompasses approximately 135 km², is bounded by Latitudes 48°10′N to 48°17′N and Longitudes 85°11′W to 85°20′W. Mapping was conducted at 1:15 840 (1 inch to 1/4 mile) scale, utilizing, for the most part, pace–and–compass traverses.

An all–season road originating from Highway 17 transects the southern part of Keating Township en route to Muscocho Explorations Limited's Magnacon Mine in the Mishibishu Lake area. Logging roads provide limited access via four–wheel drive and off–road vehicles. Iron Lake and some of the larger lakes are navigable with canoes, as is the University River. Areas north of Iron Lake and parts of Legarde Township to the south are accessible only by helicopter.

The most comprehensive work previously completed within the map area was by Bennett and Thurston (1977), who produced a 1:63 360 (1 inch to 1 mile) scale map and report of the Mishibishu and Kabenung Lakes area. They considered supracrustal rocks in the Keating Township area to be part of the Kabenung Lake Belt. Correlation of stratigraphy and structure of the Keating Township area with recent work in the Michipicoten Greenstone Belt (Sage 1986) suggests that the Kabenung Lake Belt is not a distinct belt. In this work, the Kabenung Lake Belt is interpreted as the western extension, and more distal equivalent, of the Michipicoten Greenstone Belt.

MINERAL EXPLORATION

Information on mineral exploration activity is taken from the Assessment Files Research Office, Ontario Geological Survey, Toronto, and from Assessment Files, Resident Geologist's Office, Ontario Ministry of Northern Development and Mines, Wawa.

The first exploration in the area, for iron ore and gold, occurred at the beginning of the twentieth century. Between 1898 and 1902, Ontario Mining

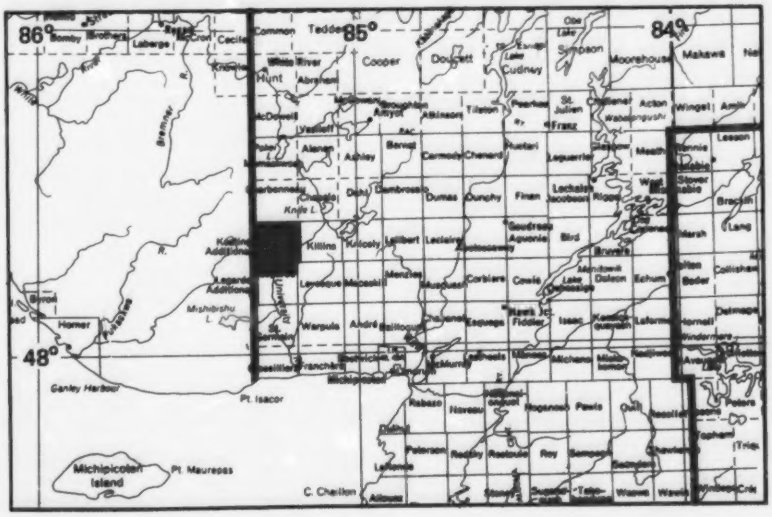


Figure 36.1. *Location map for the Iron Lake Area. Scale: 1:1 584 000 or 1 inch to 25 miles.*

Company completed a considerable amount of surface work, which included stripping, test pits and shafts, on a wide band of iron formation located approximately 1 km west of Iron Lake. The Minnesota Mining Company also did some work on the same iron formation immediately west of Minnesota Bay of Iron Lake between 1900 and 1903. The Clergue Company drilled one diamond–drill hole the following year, which revealed only small pockets of hematite.

In 1902, the Lake Superior Company purchased from the Ontario Mining Company 17 claims, comprising 623 acres, extending from west of the Keating Additional Township boundary to the edge of Iron Lake. Between 1909 and 1911, five diamond–drill holes totaling 1094 m were drilled through the iron formation and revealed two 7 m sections consisting of 39 percent Fe and 46 percent Fe, respectively.

In 1946, Algoma Ore Properties Limited (now Algoma Steel Corporation Limited, Algoma Ore Division) staked a group of claims which adjoined the easterly end of the Lake Superior Company property and extended in a northeast direction for 4 km, including Minnesota Bay. They also made an arrangement with Algoma Central Railway which gave Algoma Ore Properties Limited the exclusive prospecting rights for a total of five townships, including Keating. During 1947 and 1948, they conducted a magnetometer survey and drilled nine diamond–drill holes for a total of 2118 m. One quartz vein measuring 4 m wide had 0.13 ounce gold per ton over 1 m. Nevertheless, the drilling did not prove sufficient mineralization to warrant further exploration.

From the 1930s to the 1960s, geological mapping and sampling were completed by a series of mining companies including: O'Brien Gold Mines Limited and Algoma Central Railway (1936 to 1937); Jalore Mining Company Limited (1952); Jalore Mining Company Limited, Algoma Central Railway and Algoma Ore Properties Limited (1955); Canadian Pacific Railway Company (1957), and Algoma Central Railway (1963).

In 1967, Acme Gas and Oil Company Limited contracted Canadian Aero Mineral Surveys Limited to fly a magnetometer, electromagnetic and radiometric survey of all Algoma Central Railway townships including Keating. Umex Corporation Limited followed with a ground magnetometer and electromagnetic survey in Keating Township in 1974. They drilled two diamond–drill holes for a total of 193 m. Between 1978 and 1983, Noranda Exploration Limited completed a ground magnetometer, electromagnetic, and induced polarization survey and drilled four diamond–drill holes (total 414 m) in Keating Additional Township, north of Yaskovitch Lake. Amex Minerals Exploration Limited conducted electromagnetic surveys and drilled one diamond–drill hole during 1979 and 1980.

In 1982, International Corona Resources Limited obtained the exploration rights for 13.5 townships, including Keating, from Algoma Central Railway. In 1983, they contracted Dighem Surveys and Processing Incorporated to fly an electromagnetic, magnetometer and resistivity survey. Manwa Exploration Services Limited operated the exploration program, which included geological mapping, soil and rock geochemistry, and a ground magnetometer and electromagnetic survey. In 1984, they drilled nine diamond–drill holes for a total of 914 m. Drilling concentrated on the footwall of the Iron Lake Iron Formation, where a weakly auriferous zone of quartz veining is hosted by felsic volcanic rocks, felsic dikes and sediments.

Tundra Gold Mines Limited contracted Aerodat Limited to fly an electromagnetic and magnetometer survey in 1983. The following year they conducted a soil sampling survey and prospecting in the southeastern corner of the township and in the area farther to the west, where they are currently involved in surface exploration.

GENERAL GEOLOGY

METAVOLCANIC ROCKS

Mafic to Intermediate Metavolcanic Rocks

Mafic to intermediate volcanic rocks comprise the most abundant lithology in the map area (Figure 36.2). Massive flows are predominant; however, primary features present include pillows, pillow breccia, and vesicles commonly infilled with quartz and carbonate. Plagioclase crystal tuff units, locally containing lapilli and bomb–size fragments, are less common. Typically, individual flow and pyroclastic deposits were not delineated during the mapping, due to the paucity of continuous outcrop and limited development of primary structures. Metavolcanic rocks with abundant 1 to 2 cm plagioclase phenocrysts serve as excellent stratigraphic marker horizons which define an approximately east–striking stratigraphy.

Pillow stacking within flows and graded bedding within tuffs indicate that the metavolcanic rocks in the northern part of the map area young to the south and that the metavolcanic rocks in the south young to the north. Thus, the stratigraphy is divided into a south–younging Northern Terrane and a north–younging Southern Terrane (Figure 36.2). Preliminary field observations suggest that within each terrane, a lower Fe–rich sequence (tholeiitic?) is overlain by a plagioclase–phyric sequence (calc–alkaline?).

Felsic to Intermediate Metavolcanic Rocks

Felsic to intermediate metavolcanic rocks are much less voluminous than mafic to intermediate metavolcanic rocks. Pyroclastic tuff breccias are dominant

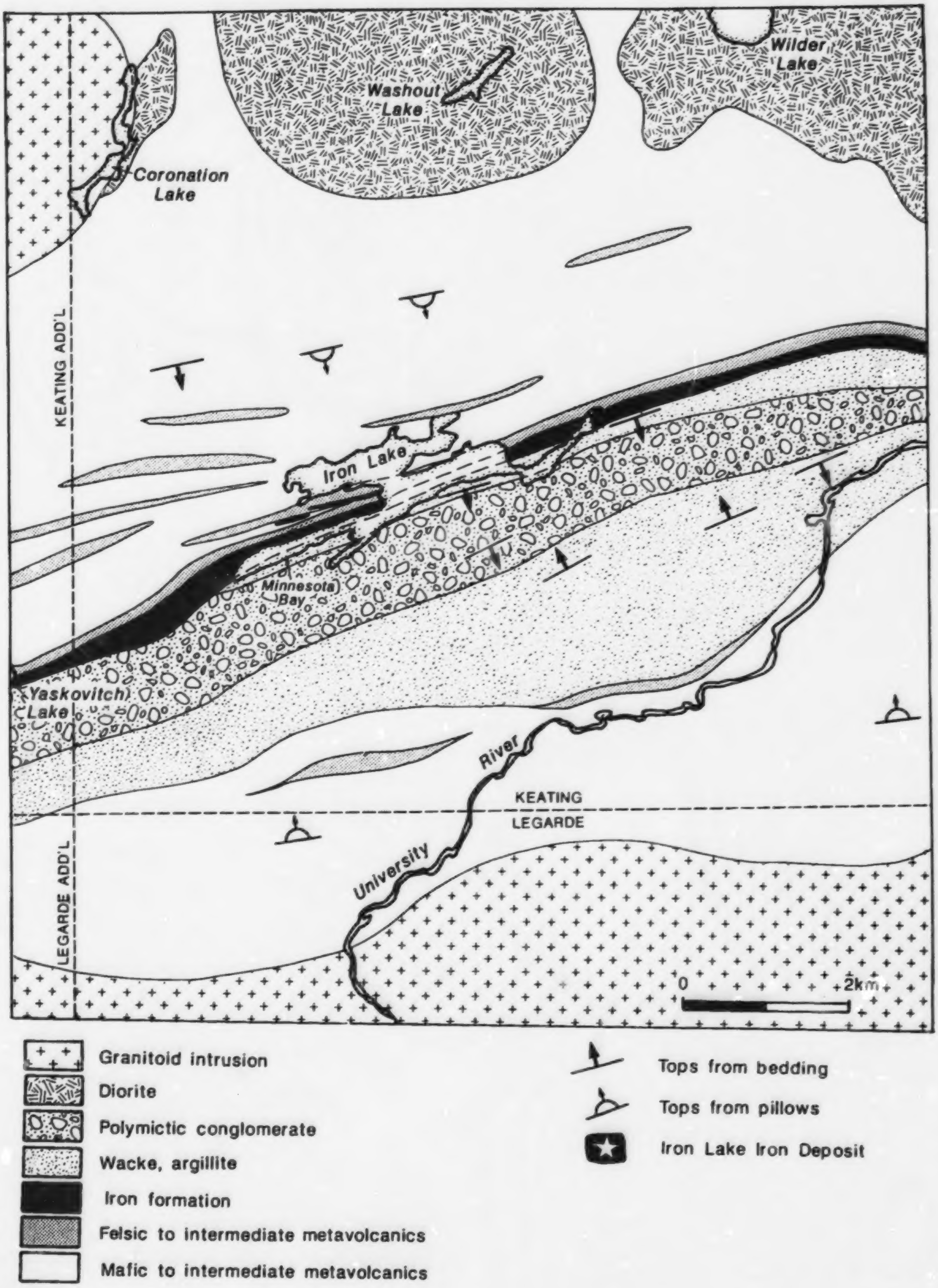

Coronation Lake
Washout Lake
Wilder Lake
KEATING ADD'L
Iron Lake
Minnesota Bay
Yaskovitch Lake
River
University
KEATING
LEGARDE
LEGARDE ADD'L
0
2km
Granitoid intrusion
Diorite
Polymictic conglomerate
Wacke, argillite
Iron formation
Felsic to intermediate metavolcanics
Mafic to intermediate metavolcanics
Tops from bedding
Tops from pillows
Iron Lake Iron Deposit

Figure 36.2. *Generalized geology of the Iron Lake Area.*

and consist of lenticular fragments which range in size from ash to bombs. Fragments are monolithic and more felsic in composition than matrix material. Quartz crystal tuffs are less common and may be difficult to discern from concordant quartz porphyritic intrusions. Rare, massive, aphanitic flow rocks are also present.

Individual felsic to intermediate metavolcanic units are thin, ranging from 5 to 50 m, and are concentrated stratigraphically above the mafic to intermediate metavolcanic sequence.

METASEDIMENTARY ROCKS

Chemical Metasedimentary Rocks

A Michipicoten–type iron formation (Goodwin 1962) strikes through the map area in an east–west orientation. It forms a prominent ridge, over 60 m in height, which is best exposed on the northern shore of Minnesota Bay. Field mapping, supported by recent Airborne Electromagnetic Survey Maps 81004 and 81014 (Ontario Geological Survey 1987), indicates that the Iron Lake Iron Formation is continuous across the township, measures up to 350 m in thickness, and becomes much thinner laterally to the east and west. Several thin iron formations crop out immediately north of the main iron formation. Generally, they measure less than 10 m in thickness and are discontinuous in strike length.

The main iron formation is located stratigraphically above the felsic to intermediate metavolcanic rocks. It is predominantly oxide facies and consists of very thinly bedded magnetite–hematite and chert (jasper is locally present). A systematic stratigraphic sequence is observed within the iron formation and consists of a carbonate facies base, which is only locally present and composed of variably weathered siderite interbedded with chert, chert–magnetite layers which grade into chert–hematite layers, and a cap of massive to brecciated chert.

Clastic Metasedimentary Rocks

Overlying the iron formation and the metavolcanic rocks is a clastic metasedimentary sequence comprising wacke, polymictic conglomerate, and interbedded wacke and argillite. Clasts within the polymictic conglomerate range in composition from mafic to intermediate metavolcanic rocks, felsic to intermediate metavolcanic rocks, iron formation, chert, granitoids, felsic porphyry, and quartz. A gradation in grain size and texture is observed from clast–supported, cobble–size clasts in the north to matrix–supported, pebble–size clasts in the south. Thus, a proximal sedimentary facies grades into a more distal facies, indicating a source to the north.

Interbedded wacke and argillite crop out south of the conglomeratic rocks. Graded bedding within the wacke/argillite sequence generally indicates tops to the south, which is consistent with the younging direction interpreted from sedimentary facies within the conglomerate. Local bedding reversals indicated by a few beds which grade to the north may be explained by observed tight to isoclinal folding. A thin (less than 100 m) unit of south–younging wacke beds located immediately north of the conglomerate is believed to be part of the proximal sedimentary facies. The conglomerate/wacke/argillite sequence is correlative with the Dore sediments (Cooke 1937) in the core of the Michipicoten Greenstone Belt.

INTRUSIVE ROCKS

Early Mafic Intrusions

Mafic to intermediate metavolcanic rocks are intruded by fine– to medium–grained mafic sills. The average thickness of the mafic intrusions is typically less than 5 m. Bennett and Thurston (1977) recognized the intrusive nature of these rocks by their massive and homogeneous texture and blocky jointing. Contacts of the intrusive rocks are generally sheared and concordant with the stratigraphy; however, thin apophyses may intrude the country rocks. Although present within the mafic to intermediate metavolcanic rocks of the Southern Terrane, mafic sills are more abundant in the Northern Terrane where they are estimated to constitute up to 50 percent of the stratigraphy.

The mafic sills possess a metamorphic mineral assemblage and weak foliation, which are similar to those developed in the mafic to intermediate metavolcanic rocks. The sills have, therefore, probably been subjected to the same regional metamorphic and deformational event. The spatial and temporal association with the mafic to intermediate metavolcanic rocks suggests that the mafic sills may have served as a feeder system to the metavolcanic sequence.

Early Felsic Intrusions

Plagioclase and/or quartz porphyritic rocks of felsic composition intrude both the metavolcanic and metasedimentary sequences. The phenocrysts, which range in size from less than 1 mm to 1 cm and constitute up to 75 percent of the rock, are enclosed by an aphanitic to medium–grained matrix. The felsic porphyries have an average thickness of less than 5 m and possess contacts which are sharp and concordant with stratigraphy. Like the mafic sills described above, these early felsic sills exhibit a similar metamorphic grade and foliation as the felsic metavolcanic rocks and are interpreted as synvolcanic intrusions.

Late Mafic Intrusions

A large mafic intrusion, measuring approximately 32 km^2, crops out in the Wilder Lake area and was named the Wilder Lake Complex by Bennett and Thurston (1977). The Wilder Lake Complex is predominantly of dioritic composition and consists of hornblende and plagioclase with minor pyroxene, biotite, and quartz. Rocks of the complex are medium to coarse grained with local pegmatitic and hornblende porphyritic phases. Amphibolitic inclusions and granitic intrusions of variable composition are included as part of the Wilder Lake Complex.

Field investigations during 1988 also delineated a second intrusion of similar composition and texture. This mafic intrusion extends west of Wilder Lake to Confederation Lake and has been named the Washout Lake Complex. The Washout Lake Complex has an oval shape with an estimated surface area of 16 km^2.

Both complexes are expressed as positive aeromagnetic anomalies on Total Intensity Magnetic Survey Maps 81003 and 81004 (Ontario Geological Survey 1987) and extend north of Keating Township. Smaller mafic intrusions of gabbroic composition are found throughout the map area.

Granitoid Intrusions

The granitoid intrusion south of the greenstone belt consists of foliated to gneissic tonalite to quartz diorite. Local phases of granodiorite composition are present. The tonalite to quartz diorite is generally medium grained and texturally variable, ranging from equigranular to plagioclase porphyritic. The mafic mineral content ranges from 5 to 25 percent, and biotite, if present, is typically less abundant than hornblende. The contact between the southern granitoid and the greenstone belt is marked by a transition zone of aplitic–textured granitoid; felsic apophyses, which are locally pegmatitic; rafted inclusions of amphibolitized country rock, and mafic intrusions. An amphibolite facies metamorphic aureole extends for up to 1 km into the country rock. The northern granitoid intrusion which crops out at Confederation Lake is similar in composition and texture to the southern granitoid intrusion, and also exhibits a contact metamorphic and strain aureole.

Diabase Dikes

Late Archean diabase dikes crosscut all lithologies in the map area. Two major trends were observed, producing a conjugate set at 025° and 340°. East– and north–striking dikes are less common. The dikes contain variable proportions of plagioclase, pyroxene, olivine, hornblende, and quartz. They are massive, aphanitic to medium grained, and locally plagioclase porphyritic. Dike thickness ranges from less than 1 m up to 100 m. Contacts are sharp and may exhibit offsets, especially when a competency contrast due to a change in lithology occurs along intrusion paths. The smaller dikes possess a thin chilled margin, typically less than 2 cm thick; however, the larger dikes may bake country rocks, producing a zone up to 5 m thick. Epidote and quartz veining are abundant within many of the dikes. Diabase dikes may occupy early ductile or brittle structures. Typically, outcrops form lineaments represented as topographic highs and positive aeromagnetic anomalies.

STRUCTURAL GEOLOGY

FOLIATIONS AND LINEATIONS

All supracrustal rocks in the map area (excluding the amphibolite grade metamorphic aureoles produced by the granitoid intrusions to the south and at Coronation Lake) possess a weakly to moderately developed penetrative foliation and have been subjected to greenschist facies metamorphism. This planar fabric is defined by the parallel growth of platy and acicular minerals, such as chlorite, actinolite, and sericite (hornblende is found within the metamorphic aureoles). The regional foliation strikes approximately east and dips steeply to the north in the Southern Terrane and steeply to the south in the Northern Terrane (Figure 36.3). Generally, foliation parallels or lies at a low angle to bedding.

Lineations associated with this regional penetrative fabric are typically weakly developed to indistinct, except along lithological contacts. A stretching lineation is defined by the linear alignment of platy and acicular minerals, plagioclase, and quartz grains, and, when present, by primary structures such as clasts, fragments, phenocrysts, and amygdules. The regional lineation plunges moderately to the west and visual estimates of the lineation:foliation (L:S) ratio (the relative prominence of the stretching lineation (L) in comparison to the foliation (S) (Schwerdtner *et al.* 1977)) is typically L less than S. Locally, subvertical crinkle and crenulation lineations appear to overprint the west–plunging regional lineation.

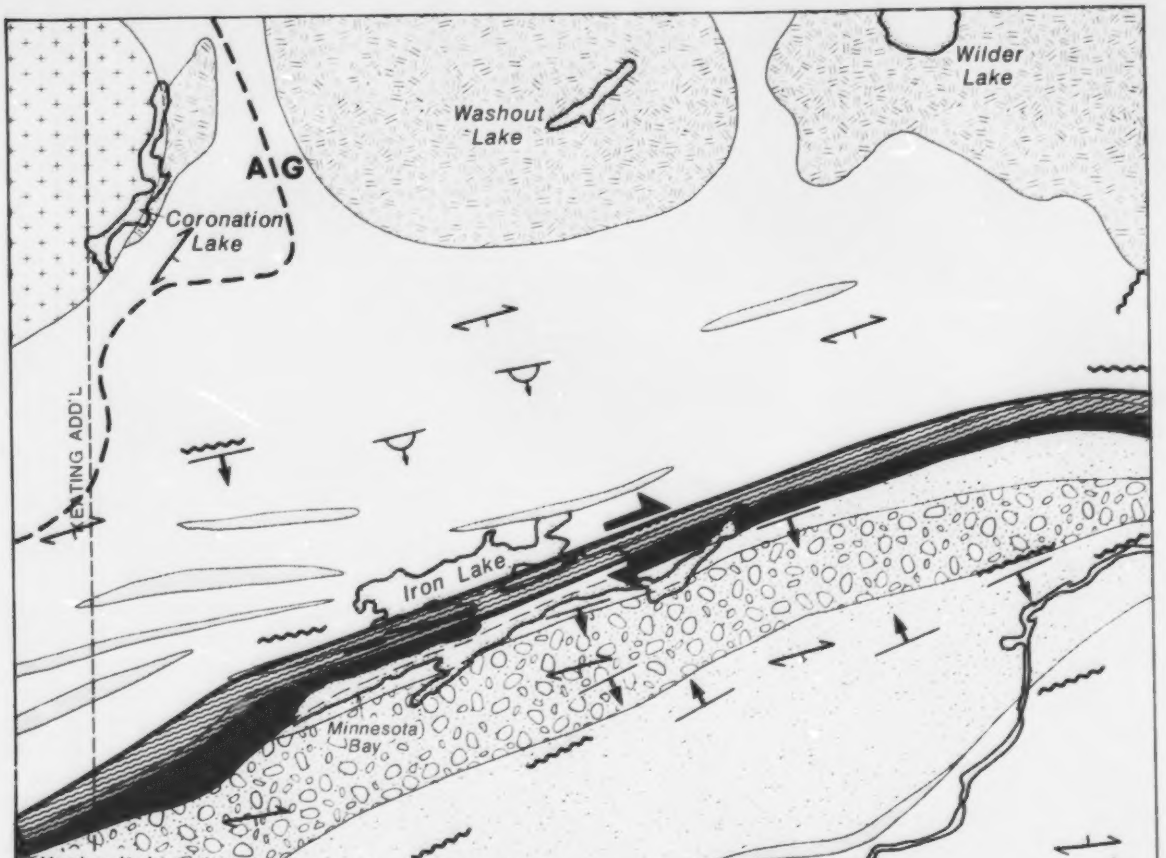
FOLDING

Minor Folds

Minor folding is present but not common in the map area. Two types of minor folds (metre scale) were mapped: 1) asymmetric drag folds produced during shearing, with fold axes perpendicular to shear direction; and 2) symmetric folds spatially associated with lithological contacts, with fold axes parallel to shear direction. Development of the latter type of fold suggests that folding was not a product of shearing but pre–dated it, with the fold limb subsequently yielding to shearing. These fold axes are not only parallel to the stretching direction in the shear zones, but coaxial with the regional stretching lineation.

Major Folds

Bennett and Thurston (1977) interpreted the reversal of younging directions in the Northern and Southern terranes to reflect a major synclinal structure and placed the synclinal axis symmetrically


Wilder Lake
Washout Lake
A G
Coronation Lake
KEATING ADD'L
Iron Lake
Minnesota Bay
Yaskovitch Lake
River
University
KEATING
LEGARDE
LEGARDE ADD'L
G
A
0
2km
Foliation, with dip direction indicated
Local high strain zone
Broad high strain zone (Iron Lake Deformation Zone)
Amphibolite–greenschist facies boundary

For geological legend, see Figure 36.2.

Figure 36.3. *Structural geology of the Iron Lake Area.*

within the conglomeratic package. This interpretation is problematical because the sedimentary sequence as a whole exhibits a proximal–distal, north to south relationship, with an overall south–younging direction. Although a major upright synclinal structure may account for differences in stratigraphic younging direction between the two terranes, an alternative explanation envisages the juxtaposition of opposite younging terranes during tectonic movement.

HIGH STRAIN ZONES

High strain zones are recognized as highly strained rocks exhibiting a penetrative foliation, which becomes more intensely developed from boundary to centre of the zone. These zones are typically strata–parallel and concentrated along lithological boundaries, and deformation is brittle–ductile. Original lithologies are difficult to identify within high strain zones as deformation and associated hydrothermal alteration often obscure and obliterate primary mineralogies and textures, locally producing a tectonic banding.

Two types of high strain zones were recognized in the map area: 1) local zones exhibiting oblique–slip movement; and 2) a broad zone exhibiting strike–slip movement, named the Iron Lake Deformation Zone (ILDZ).

The first type of high strain zone are local zones which measure less than 25 m in width and typically are composed of only one brittle–ductile shear. Strong stretching lineations (L=S) plunge moderately to the west, indicating oblique movement along the zones. Kinematic indicators were not observed. The contact between the southern granitoid intrusion and the greenstone belt is also highly strained. Deformation along this contact is similar to the local zones within the supracrustal rocks, and a strong stretching lineation which plunges moderately to the west is observed. Shearing penetrates the external granitoid to at least the southern margin of the mapping.

The Iron Lake Deformation Zone (ILDZ) is the best example of the second type of high strain zone. It consists of an anastomosing series of brittle–ductile shear zones which envelope relatively undeformed lithons. The ILDZ transects Iron Lake in an east–west orientation across Keating Township, with a minimal width of 300 m. It occurs at the top of the metavolcanic sequence in the Northern Terrane and below the Iron Lake Iron Formation; however, it may be slightly discordant to stratigraphy.

Stretching lineations near the boundary of the ILDZ are subhorizontal; however, near the centre of the zone, a subvertical crinkle/crenulation lineation overprints the subhorizontal linear feature. This is interpreted as a late stage phenomenon in which the zone locks during the waning phases of predominantly subhorizontal ductile deformation, producing crinkles and crenulations perpendicular to the shear transport direction. Subvertically plunging, asymmetric folds are consistent with subhorizontal movement. Kinematic indicators include Z–folds and foliation fish which give a consistent dextral sense of displacement.

Two discordant zones located north of the ILDZ are comparable in size to the local high strain zones, yet exhibit subhorizontal dextral displacement, based on C–C'–fabric relationships, similar to the ILDZ.

ECONOMIC GEOLOGY

Archean lode gold deposits throughout the Superior Province of Canada are associated with deformation zones (Colvine *et al.* 1988). To date, gold occurrences in the Wawa Gold Camp have been restricted to deformation zones. The ILDZ is favourably located between the Goudreau–Lochalsh Deformation Zone to the east and the Mishibishu Deformation Zone to the southwest.

Carbonatization is coincident with the highly strained rocks enveloped by the ILDZ. A broad calcite alteration is dominant near the boundary of the zone, whereas ankerite is present near the centre. Locally, primary mineral assemblages control some types of alteration assemblages observed within the zone. Protoliths of felsic composition exhibit sericitization and rocks of more mafic composition yield to chloritization.

Quartz veins emplaced within the ILDZ are generally folded, boudinaged, and rotated, suggesting a pre– to syn–tectonic temporal relationship with the development of the zone. Pyrite is the dominant sulphide mineral and, when present, is typically found as fine–grained, disseminated cubes. An exception to this habit are pods of massive pyrite within carbonate facies iron formation which crops out on a small lake due north of Minnesota Bay. Here, the carbonate iron formation, which is as a distinct body separate from the main oxide iron formation, is affected by the ILDZ and is host to quartz–tourmaline veining. Cellular textures present within the carbonate facies iron formation are a result of preferential weathering of disseminated pyrite crystals.

Field observations indicate that most of the iron formation is relatively undeformed; however, because of the anastomosing geometry of the ILDZ, the base of the main iron formation and the underlying subordinate iron formations may be transected by the ILDZ.

Local high strain zones, although smaller in size than the ILDZ, exhibit similar deformation and alteration characteristics. The loci of the these zones are typically concentrated along lithological contacts where a competency contrast exists. The tectonic permeability produced in the zones enhances the passage of hydrothermal fluids. These zones are typically carbonatized (calcite and/or ankerite), with variable degrees of sericitization and chloritization.

Quartz veining and sulphide mineralization are similar to the ILDZ but less extensive.

Felsic pyroclastic metavolcanic rocks, concentrated at the stratigraphic top of the metavolcanic sequence in both the Northern and Southern terranes, are potential hosts for volcanic–associated, base–metal, massive sulphide mineralization. No such mineralization, however, was observed during the field work.

The Wilder Lake Complex and the Washout Lake Complex warrant testing for platinum group elements; however, magmatic sulphides or sulphides associated with pegmatitic phases were not found during the field season.

The main iron formation consists predominantly of alternating magnetite–hematite and chert layers. This deposit is thinner and much leaner than the Michipicoten–type iron ore deposits in the central part of the Michipicoten Greenstone Belt. Nevertheless, the iron formation serves as a favourable host for gold mineralization where transected by the ILDZ.

Based on observed deformation and alteration characteristics mapped at 1:15 840 scale and comparison of these features with known gold occurrences within the Wawa Gold Camp, the economic potential for gold mineralization, especially within the ILDZ and local high strain zones, warrants further systematic detailed mapping.

ACKNOWLEDGMENTS

The author would like to acknowledge the personnel of the following companies and government ministries for their cooperation and assistance provided during the field season: Flanagan McAdam Resources Incorporated; Granges Explorations Limited; Ministry of Natural Resources, Wawa; Muscocho Explorations Limited; the Wawa and Sault Ste. Marie Resident Geologists' Offices; Tundra Gold Mines Limited; and Viking Helicopters Limited. Special thanks are extended to Jane Howe, David Evans, Michele Cote, and Robert Dufton, who provided able field assistance.

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37. Project Number 87–3. The Geological and Structural Setting of Gold Mineralization in the Missanabie–Renabie District of the Michipicoten Greenstone Belt, Wawa, Ontario

K.B. Heather and Shane Buck

Geologists, Precambrian Geology Section, Ontario Geological Survey, Toronto.

INTRODUCTION

The work summarized here represents the continuation of studies designed to evaluate the metallogeny of gold within the Wawa Gold Camp, which comprises the Mishibishu Lake area (Heather 1985, 1986), the Michipicoten area, the Goudreau–Lochalsh area (Arias and Heather 1987; Heather and Arias 1987), and the Missanabie–Renabie district. The current study focusses on the Missanabie–Renabie district, which is located approximately 70 km northeast of Wawa and is accessible via Highway 651 from Highway 101. The Missanabie–Renabie district is located on the eastern end of the Michipicoten Greenstone Belt and includes portions of the townships shown on Figure 37.1 and in Figure 37.2. The purpose of the current study is five fold:

1. to evaluate the gold potential of the Missanabie–Renabie district
2. to document any eastward extension of either the Goudreau Lake Deformation Zone or the Cradle Lakes Deformation Zone (Figure 37.3), as defined in the Goudreau–Lochalsh area (Arias and Heather 1987; Heather and Arias 1987)
3. to document any variations in the bedrock geology, structural style, alteration or metamorphic grade eastwards from the Goudreau–Lochalsh area
4. to put the Renabie Gold Mine, the largest producer of gold in the Michipicoten Greenstone Belt, into a regional geological and structural context,
5. to add to the overall understanding of the metallogeny of gold in the Wawa Gold Camp

METHODOLOGY

Systematic collection of lithological, structural, alteration, metamorphic, and mineral–occurrence data was completed during the summer of 1988 for Riggs, West, southern Glasgow, southern Meath, southern Rennie, and northern Stover townships, at a scale of 1:15 840 (Figures 37.2 and 37.3). Map-

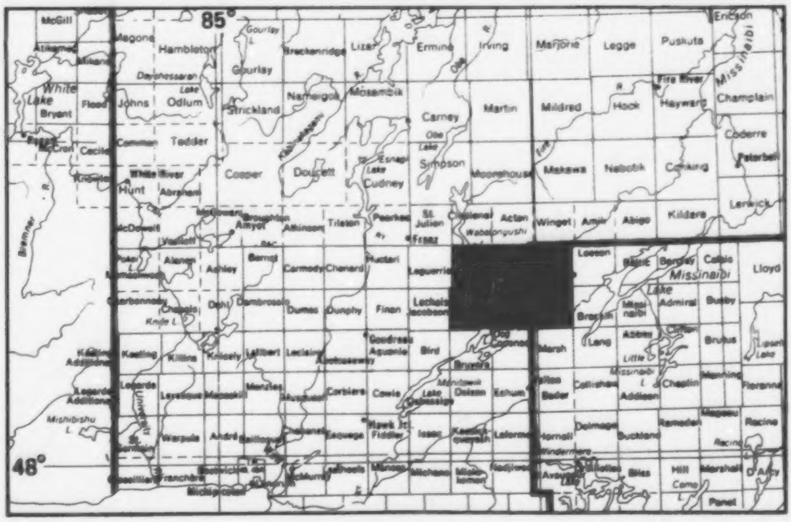

85°
48°
McGill
Megone
Hambleton
Gourlay L.
Gourlay
Breckenridge
Lizar
Ermine
Irving
Marjorie
Legge
Puskuta
Ericson
Missinaibi
Dayohessarah Lake
White Lake
Bryant
Flood
Johns
Odlum
Strickland
Nameigos
Mosambik
Carney
Obe Lake
Martin
Mildred
Hook
Fire River
Hayward
Champlain
Coderre
Todder
Cecile
Cooper
Doucett
Esnagi Lake
Cudney
Simpson
Moorehouse
Makawa
Nebotik
Peterbell
White River
Hunt
Abraham
Tristan
St. Julien
Franz
Acton
Wabatongushi
Winget
Abigo
Kildare
Lerwick
McDowell
Atkinson
Lawson
Bertrand
Barclay
Lloyd
Alanen
Ashley
Bernot
Carmody
Chenard
Hutton
Missinaibi
Lake
Admiral
Busby
Knife L.
Dahl
Dumas
Dunphy
Finan
Brackin
Abbey
Bruyère
Lang
Marsh
Little Missinaibi L.
Goudreau
Aguonie
Bird
Keating
Killins
Lalibert
Leclaire
Corbiere
Cowie
Menzies
Callinan
Chaplin
Addison
Mishibishu L.
Hawk Jct.
Fiddler
Isaac
Racine
Warpula
Andre
Franchère
Michipicoten
Dolmage
Buckland
Hornell
Wemyss
Bliss
Hill
Marshall
D'Arcy
Panet

Figure 37.1. *Location map for the Missanabie–Renabie district, District of Algoma, Ontario. Scale: 1:1 584 000 or 1 inch to 25 miles.*

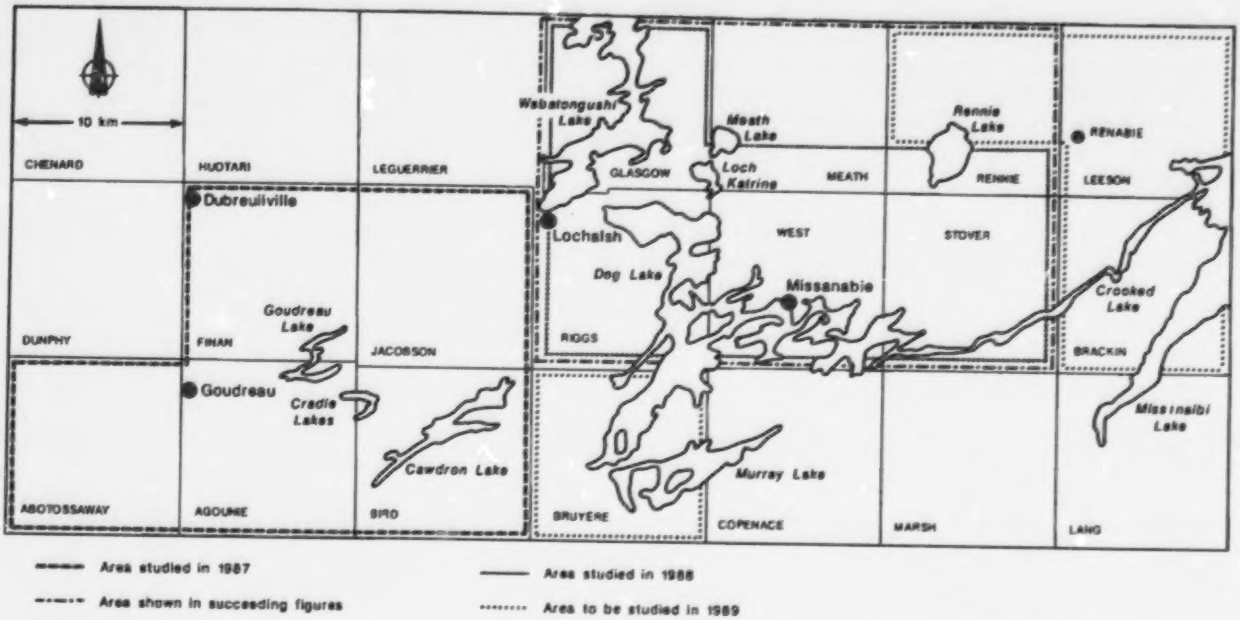

10 km
CHENARD
HUOTARI
LEGUERRIER
Wabatongushi Lake
GLASCOW
Mesth Lake
Loch Katrine
MEATH
Rennie Lake
RENNIE
RENABIE
LEESON
Dubreuilville
Lochalsh
WEST
STOVER
Dog Lake
Missanabie
Crooked Lake
Goudreau Lake
DUNPHY
FINAN
JACOBSON
RIGGS
BRACKIN
Goudreau
Cradle Lakes
Missinaibi Lake
Cawdron Lake
Murray Lake
ABOTOSSAWAY
AGOUNIE
BIRD
BRUYERE
COPENACE
MARSH
LANG
Area studied in 1987
Area shown in succeeding figures
Area studied in 1988
Area to be studied in 1989

Figure 37.2. *Township location map for the Goudreau-Lochalsh and Missanabie-Renabie districts.*

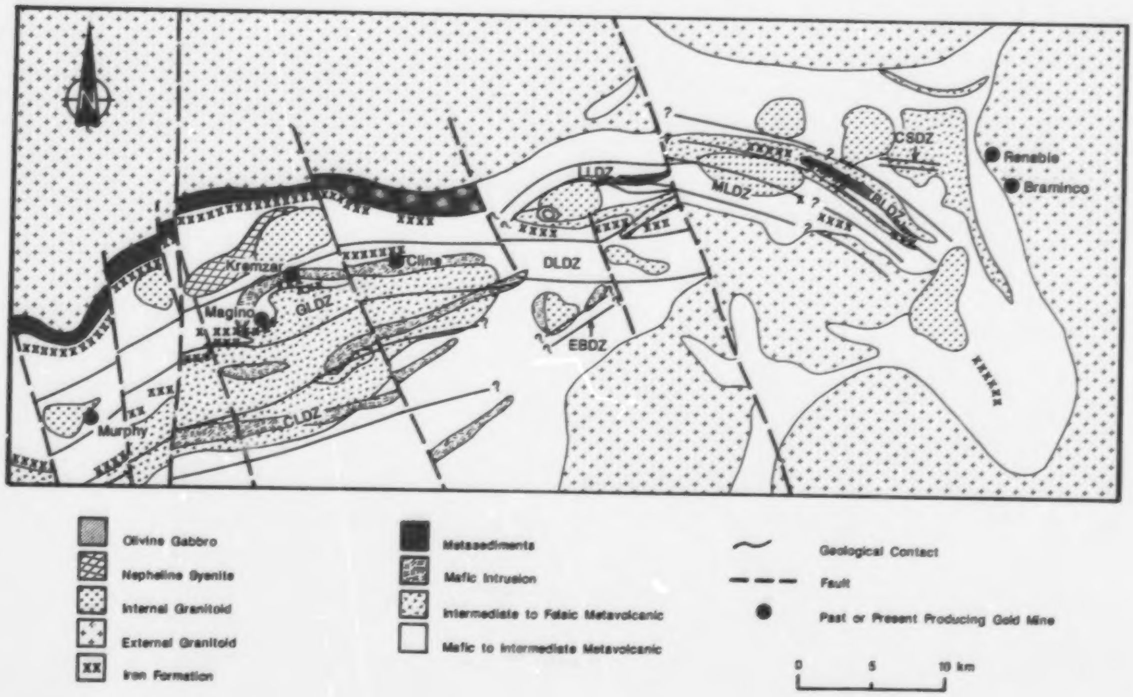

CSDZ
Renabie
Braminco
LDZ
MLDZ
BLDZ
Kremzar
Cline
DLDZ
Magino
GLDZ
EBDZ
Murphy
CLDZ
Olivine Gabbro
Nepheline Syenite
Internal Granitoid
External Granitoid
Iron Formation
Metasediments
Mafic Intrusion
Intermediate to Felsic Metavolcanic
Mafic to Intermediate Metavolcanic
Geological Contact
Fault
Past or Present Producing Gold Mine
0
5
10 km

Figure 37.3. *Regional geology and structure for the Goudreau-Lochalsh and the Missanabie-Renabie districts.*

ping of northern Glasgow Township was completed at a reconnaissance scale, while northern Meath and Rennie townships were not mapped due to poor access and extensive glacial overburden. No work was done in Brackin, Marsh, or Lang townships. Some reconnaissance and detailed work was started in Leeson Township in the vicinity of the Renabie Gold Mine (Figure 37.3).

Modifications to the existing 1:15 840 lithological maps (Bruce 1942; Riley 1971; Bennett 1978; and Srivastava and Bennett 1978) were made when warranted; however, changes were minor. In areas of good bedrock exposure (e.g. glaciated lakeshore outcrops or mechanically stripped outcrops), more detailed-scale mapping and data collection were completed. The majority of historic gold occurrences were visited during the current survey; however, many of these now consist of overgrown trenches and pits from which little new information could be gleaned.

MINERAL EXPLORATION

Descriptions of past mineral exploration in the Missanabie–Renabie district can be found in Coleman (1898), Willmott (1898), Thomson (1926), Burwash (1935), Bruce (1942), Horwood (1942), Bruce (1948), Riley (1971), Thurston *et al.* (1977), Bennett (1978), and Srivistava and Bennett (1978). Little exploration activity was observed during the current survey; however, there was evidence of recent bedrock stripping and winter diamond drilling. Renabie Gold Mines Limited continued gold production at a rate of 650 tons of ore per day (P. Olson, Mine Geologist, Renabie Gold Mines Limited, Missanabie, personal communication, 1988). Conquest Yellowknife Resources Limited completed a large bedrock-stripping program on their Smith Lake claims, located northwest of the Renabie Gold Mine. Canreos Minerals Limited's Braminco Mining operation, which produces silica flux and gold, was closed during the current survey. Recent stripping and evidence of diamond drilling were also observed at the Peleggi Central gold showings south of Stover Lake, and at the Ateba gold showings northeast of Dog Lake, both within Stover Township. Drilling was also done in the spring of 1988 on the northeastern arm of Dog Lake by Tundra Gold Mines Limited.

GENERAL GEOLOGY

The general geology of the area (Figure 37.4) has been documented previously at a 1:15 840 scale by Bruce (1942), Riley (1971), Bennett (1978), and Srivastava and Bennett (1978). For that reason, only a brief description is provided here.

MAFIC TO INTERMEDIATE METAVOLCANICS

The majority of Riggs, northern West, and southern Glasgow townships are underlain by basaltic to andesitic, tholeiitic to calc–alkalic (Srivastava and Bennett 1978), massive and pillowed flows with minor intercalated pyroclastic rocks (Figure 37.4). Flows are locally amygdaloidal or feldspar–phyric, with rare variolitic pillowed flows. The grain size of the flows ranges from aphanitic to coarse, with the latter being difficult to distinguish from synvolcanic, mafic sills which are common to the area. Adjacent to the Northern Batholithic Complex and the Ash Lake Pluton, the mafic flows become coarse grained amphibolites, which are locally gneissic (Figures 37.4 and 37.7).

Definition of bedding or stratigraphy within the mafic to intermediate metavolcanic package in Riggs Township was extremely difficult, while farther eastwards, in southern Rennie, West, and northern Stover townships, bedding was more readily recognizable due to the intercalation of felsic to intermediate metavolcanics and metasediments.

FELSIC TO INTERMEDIATE METAVOLCANICS

Felsic to intermediate metavolcanics are volumetrically small in Riggs, West, and southern Glasgow townships, except for a 300 to 600 m wide band along the southern portion of Lochalsh Bay in Riggs Township and a narrow band in southern Glasgow Township (Figure 37.4). These rocks consist of tuff–breccia, lapilli–tuff, crystal tuff, and minor pillowed to massive flows of andesitic to dacitic composition.

The majority of the felsic to intermediate metavolcanics are of pyroclastic origin and occur in Meath, Rennie and northern Stover townships (Figure 37.4). These rocks consist of felsic tuff–breccia, lapilli–tuff, and quartz–feldspar crystal tuff.

Bedding is locally well preserved and grading within certain pyroclastic units is easily recognizable. Previous mappers (Riley 1971; Bennett 1978) show the felsic to intermediate metavolcanics to be complexly intercalated with both mafic to intermediate metavolcanics and metasediments; however, it is not known how much of this is due to primary stratigraphic stacking or is a manifestation of later folding, shearing, transposition and faulting, all of which have been recognized in the area and are discussed below.

CLASTIC METASEDIMENTS

Clastic metasedimentary rocks underlie only a small percentage of the study area (Figure 37.4), and consist of interflow sediments, reworked pyroclastic material, and intercalated wackes, siltstones, and minor conglomerates. The latter group is volumetrically the most significant and is located in southern Rennie and northern Stover townships (Figure 37.4). Bedding is locally well preserved but grading within individual beds is unreliable due to intense folding, shearing, and local transposition.

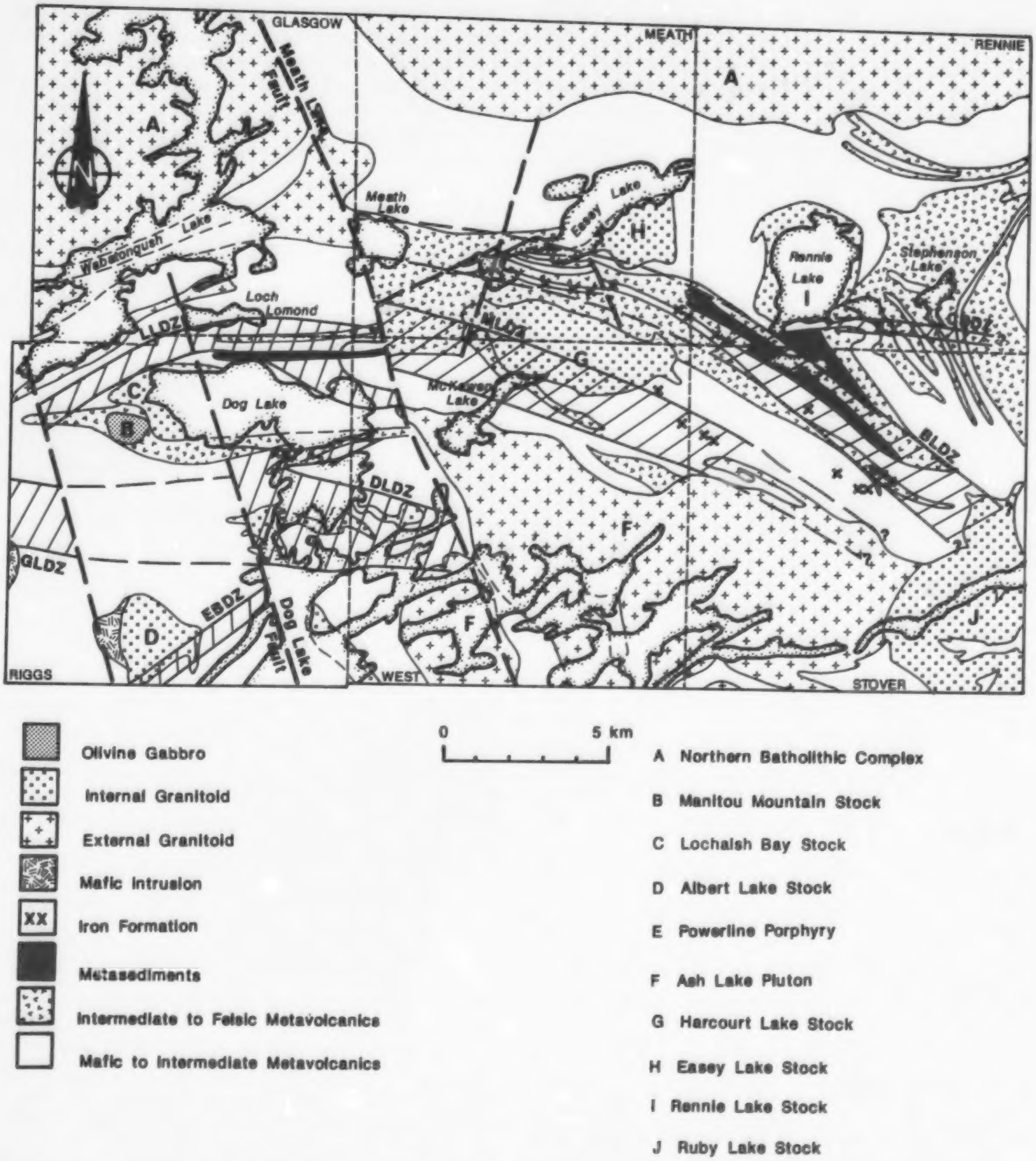

GLASGOW
MEATH
RENNIE
RIGGS
WEST
STOVER
Meath Lake Fault
Dog Lake Fault
Wabatongush Lake
Loch Lomond
Meath Lake
Easey Lake
Rennie Lake
Stephenson Lake
Dog Lake
McKeown Lake
LLDZ
MLDZ
CRDZ
BLDZ
DLDZ
GLDZ
EBDZ
A
B
C
D
E
F
G
H
I
J
N
0
5 km
Olivine Gabbro
Internal Granitoid
External Granitoid
Mafic Intrusion
XX Iron Formation
Metasediments
Intermediate to Felsic Metavolcanics
Mafic to Intermediate Metavolcanics
A Northern Batholithic Complex
B Manitou Mountain Stock
C Lochalsh Bay Stock
D Albert Lake Stock
E Powerline Porphyry
F Ash Lake Pluton
G Harcourt Lake Stock
H Easey Lake Stock
I Rennie Lake Stock
J Ruby Lake Stock

Figure 37.4. *General geology and regional deformation zones in the Missanabie–Renabie district.*

CHEMICAL METASEDIMENTS (IRON FORMATION)

Many narrow, discontinuous lenses of iron formation are found intercalated in both the mafic metavolcanic and the felsic to intermediate metavolcanic rocks (Figure 37.4). The thickness of these lean (i.e. less than 20 percent magnetite) chert-magnetite iron formations is rarely greater than one or two metres. Correlation of these iron formations with those documented to the west in the Goudreau–Lochalsh area (Sage 1984, 1985, 1987) is complicated by folding, shearing, late cross faulting and the inherent, narrow, discontinuous character of the iron formation in the Missanabie–Renabie district (Figure 37.3).

EARLY MAFIC INTRUSIONS

Metagabbro to metadiorite sills and dikes are common throughout the area but, in the absence of crosscutting relationships, are difficult to distinguish from coarse-grained, mafic metavolcanic flows. With the exception of a large, sickle-shaped body west of the Albert Lake Stock, the early mafic intrusions have been left off the general geology map (Figure 37.4) for simplicity.

EXTERNAL GRANITOIDS

Wide areas north, south and east of the Missanabie–Renabie district are underlain by extensive external granitoid complexes (Figures 37.3 and 37.4). During the current study, the Northern Batholithic Complex was examined in a reconnaissance style in the northern part of Glasgow Township. The Ash Lake Pluton (ALP) in West and Stover townships (Srivastava and Bennett 1978; Bennett 1978) was examined in more detail.

For the most part, the external granitoid rocks consist of medium- to coarse-grained biotite±hornblende tonalite to trondhjemite. These rocks are moderately to strongly foliated, with local zones of granitic and granitic-amphibolitic gneiss. Large rafts of amphibolitic volcanic rocks are common in both the Northern Batholithic Complex and the ALP. Adjacent to these rafts and along the main granitoid–supracrustal contact, the tonalite–trondhjemite appears to be contaminated by the amphibolitized rocks, producing local zones of hybrid quartz diorite.

The original external granitoid–supracrustal contact has been modified and displaced in several locations by northwest-trending structures such as the Meath Lake Fault (Figure 37.4).

INTERNAL GRANITOIDS

Six distinct granitoid stocks and numerous irregular dikes and bodies of feldspar and quartz–feldspar porphyry occur within the supracrustal rocks of the Missanabie–Renabie district (Figure 37.4). These internal granitoid rocks have been mapped in detail by Riley (1971), Srivastava and Bennett (1978), and Bennett (1978). The lithological terminology of these authors has been retained for this preliminary report.

The Lochalsh Bay Stock is a massive, unfoliated, potassium feldspar-megacrystic granodiorite with phenocrysts up to 5 cm in size. The only other similar internal granitoid, the Ruby Lake Stock, was not visited during the current study. However, the Ruby Lake Stock is described by Bennett (1978) as a massive, unfoliated, microcline-phyric, quartz monzonite, with phenocrysts up to 2 cm in size. The Rennie Lake and Easey Lake stocks consist of potassium feldspar-phyric granodiorite, but differ from the Lochalsh Bay and Ruby Lake stocks in that they are weakly foliated and their feldspar phenocrysts are much smaller (less than 3 mm). The Harcourt Lake Stock consists of massive, faintly foliated granodiorite–syenite–syenodiorite. The Albert Lake Stock consists of massive, faintly foliated, biotite trondhjemite to granodiorite and is surrounded by a weakly foliated border phase of feldspar and quartz–feldspar porphyry. Irregular dikes and bodies of feldspar and quartz–feldspar porphyry are common throughout central Riggs and northern West townships. These intrusions consist of medium- to fine-grained feldspar±quartz phenocrysts in a weakly to strongly foliated, fine-grained matrix.

LATE MAFIC TO ULTRAMAFIC INTRUSIONS

Rocks of this type in the study area include numerous diabase, lamprophyre, and ultramafic dikes, and a large olivine gabbro stock (Manitou Mountain Stock, Figure 37.4). Due to the density and extent of diabase dikes in the study area, they have been left off the general geology maps shown in Figures 37.3 and 37.4.

STRUCTURAL GEOLOGY

The following discussion summarizes the main structural observations made during the current study. This aspect of the study focused on the recognition and mapping of regional deformation zones, using the criteria established by Arias and Heather (1987). Stated simply, deformation zones define areas within which there is a greater density of discrete shear zones and the rocks collectively exhibit a higher degree of deformation than those outside the zone. This is not to say that rocks exhibiting little or no deformation can not occur within that zone. A qualitative scale of strain intensity, defined by Arias and Heather (1987), was used during the current study.

The recognition of a continuum in deformation style between brittle and ductile end members in the Goudreau–Lochalsh area (Arias and Heather 1987; Heather and Arias 1987) necessitated the systematic recording of brittle, brittle–ductile, and ductile shear zones as well as brittle fracturing in the current study area. The definitions of brittle, brittle–ductile, and ductile are consistent with those used in the Goudreau–Lochalsh area by Arias and Heather (1987), which were based on Ramsay (1980). External markers such as veins, dikes or bedding are not present in most of the brittle shear zones in the study area; therefore, it is difficult to document displacement within the zone, as required for the definition of a brittle shear zone (Ramsey 1980). However, in most cases there are, within the immediate vicinity, subparallel, ductile shear zones where displacement can be documented. The brittle zones appear to be related to the ductile shear zones and hence are called brittle shear zones.

Lineations referred to in this summary are dimensional (e.g. elongation of clasts, lapilli fragments, or mineral aggregates, etc.) or mineral lineations (e.g. long axis of quartz, feldspar, or amphibole crystals, etc.), which are interpreted to be parallel to the maximum-extension direction in the rock.

DEFORMATION ZONES

Loch Lomond Deformation Zone (LLDZ)

The Loch Lomond Deformation Zone (LLDZ) is located in the northwestern part of the map area (Figure 37.4), where it is defined by an arcuate zone of highly strained rocks, is 800 to 1600 m wide, and varies in trend from northeast through east to southeast. The western part of the LLDZ is defined by several, 1 to 30 m wide, northeast-trending ductile shear zones (Figure 37.5). Within these zones, mafic to intermediate metavolcanic rocks are deformed to chlorite or amphibole schist. Along the southern shore of Loch Lomond, the LLDZ is defined by narrow, east-trending, ductile shear zones in amphibolitic metavolcanics and a wide zone of sericite-quartz-pyrite schist south of Loch Lomond. This large zone of ductile shear is greater than 30 m in width and can be traced as far eastward as the Meath Lake Fault (Figures 37.4 and 37.5). Rocks within this zone were mapped as felsic to intermediate tuffs by Riley (1971); however, the intensity of strain developed within this zone makes it difficult to identify original lithology in the field. In the northeastern part of Dog Lake, a southeast-trending arm of the LLDZ is defined by several southeast-trending shear zones which cut both the mafic to intermediate metavolcanic rocks and a narrow band of metasedimentary rocks (Figure 37.4).

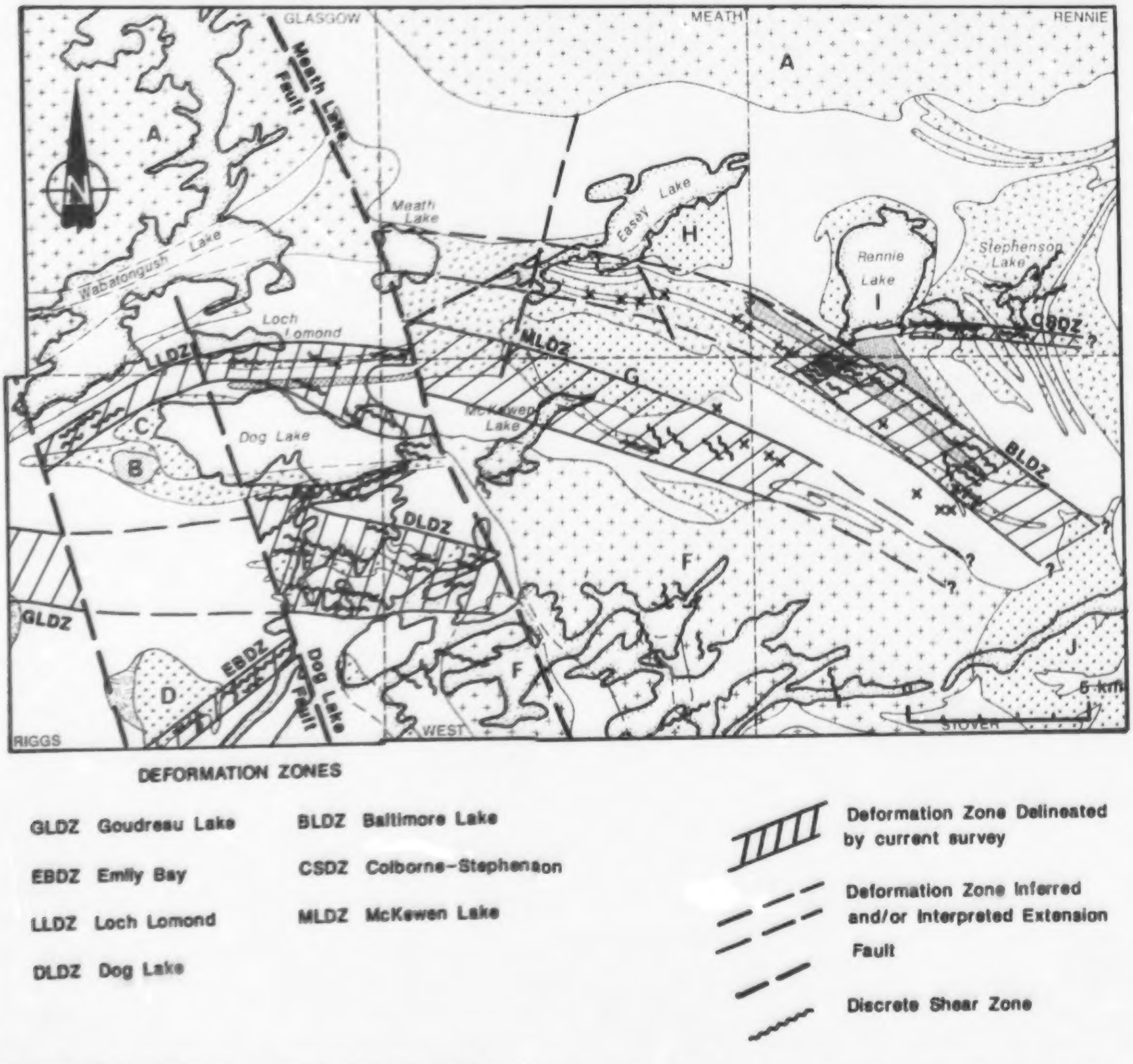

GLASGOW
MEATH
RENNIE
Meath Lake Fault
A
A
Meath Lake
Easey Lake
H
Rennie Lake
I
Stephenson Lake
CSDZ
Wabatongush Lake
Loch Lomond
LLDZ
MLDZ
G
McKewen Lake
BLDZ
C
Dog Lake
B
DLDZ
F
F
GLDZ
EBDZ
Dog Lake Fault
D
J
5 km
RIGGS
WEST
STOVER
DEFORMATION ZONES
GLDZ Goudreau Lake
EBDZ Emily Bay
LLDZ Loch Lomond
DLDZ Dog Lake
BLDZ Baltimore Lake
CSDZ Colborne-Stephenson
MLDZ McKewen Lake
Deformation Zone Delineated by current survey
Deformation Zone Inferred and/or Interpreted Extension
Fault
Discrete Shear Zone

Figure 37.5. *Discrete shear zones, regional deformation zones and general geology in the Missanabie-Renabie district.*

Outside the discrete shear zones within the LLDZ, the rocks are moderately to strongly deformed, with a well developed foliation which generally strikes parallel to the shear zones. Lineations within the LLDZ vary from moderately east-plunging in the western part to steeply east- to southeast-plunging in the eastern part (Figure 37.6). Lineations within the southeastern arm of the LLDZ plunge steeply toward the northeast (Figure 37.6).

Within the southeastern arm of the LLDZ, steep northeast-plunging lineations and kinematic indicators, such as shear folds and S–C shear fabrics, indicate a dextral, south-side-up sense of oblique displacement. Kinematic indicators are not well developed within the main part of the LLDZ, but the presence of moderately to steeply plunging lineations may indicate that movement within the LLDZ was dominantly dip slip.

Emily Bay Deformation Zone (EBDZ)

The Emily Bay Deformation Zone (EBDZ) is located on the western side of Dog Lake in southern Riggs Township (Figure 37.4). The EBDZ is a 500 m wide, east–northeast-trending (060° to 070°) zone of intense ductile shearing and weakly to strongly strained rocks. The EBDZ can be traced up to 4 km to the southwest of Dog Lake, but cannot be traced to the eastern side of Dog Lake (Figure 37.5).

The EBDZ is localized within massive to pillowed mafic metavolcanics (Figure 37.4), that are deformed to chlorite–calcite and chlorite–iron carbonate schists within several discrete ductile shear zones. These shear zones are northeast-trending and vary in width from 1 m to greater than 30 m. A second set of narrow, brittle to ductile, northwest-trending (340°) shear zones is also observed within the EBDZ, especially in the vicinities of the Emily Bay and Bankfield gold occurrences (Figure 37.5). Brittle shear zones and brittle fracturing, oriented at 060° to 070°, are well developed in rocks that exhibit weak to moderate ductile deformation.

Lineations within the EBDZ are moderately southwest-plunging in the discrete shear zones and moderately southeast-plunging in rocks outside the discrete shear zones (Figure 37.6). No reliable mesoscopic kinematic indicators were observed within the EBDZ.

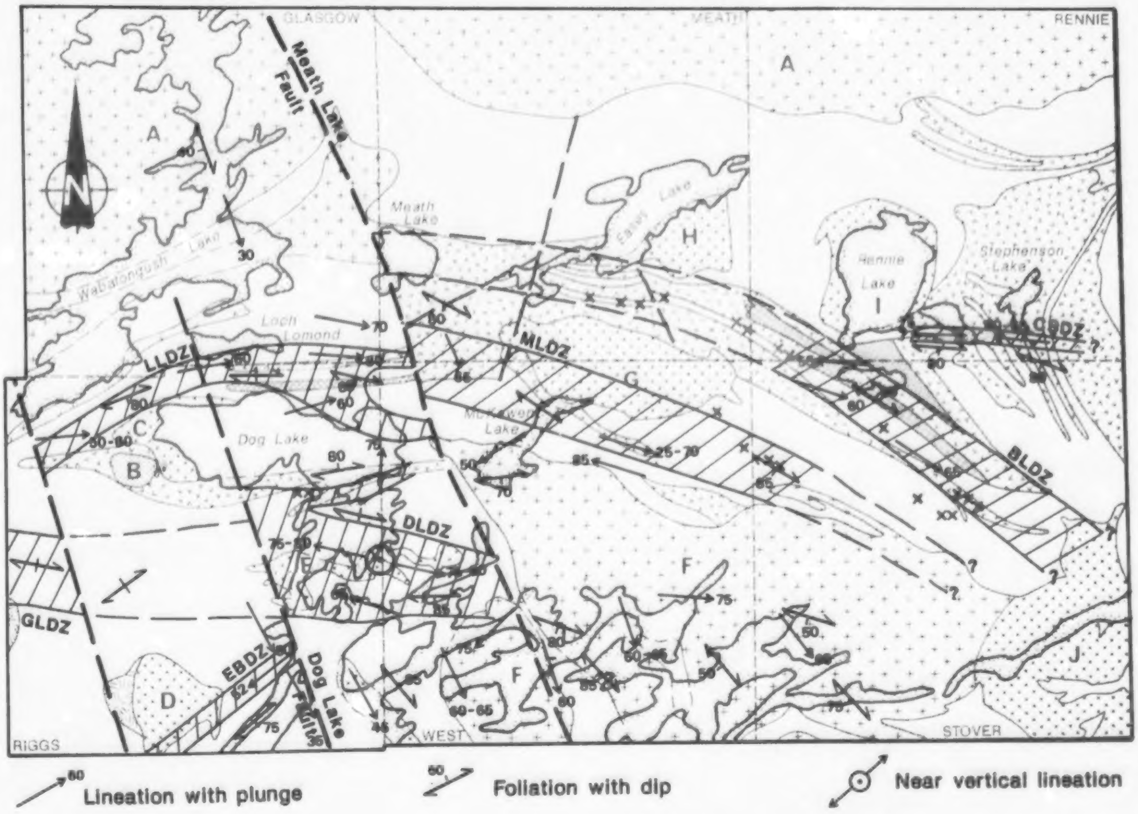

GLASGOW
MEATH
RENNIE
A
Meath Lake Fault
N
Meath Lake
Wabatongush Lake
Loch Lomond
Esau Lake
H
Rennie Lake
I
Stephenson Lake
CBDZ
LLDZ
MLDZ
G
C
B
Dog Lake
McKeown Lake
BLDZ
DLDZ
F
GLDZ
EBDZ
Dog Lake Fault
D
J
RIGGS
WEST
STOVER
Lineation with plunge
Foliation with dip
Near vertical lineation

Figure 37.6. *Foliations, lineations, regional deformation zones and general geology in the Missanabie–Renabie district.*

Dog Lake Deformation Zone (DLDZ)

The Dog Lake Deformation Zone (DLDZ) is located in the central part of Riggs and West townships, where it is defined by a 1.5 to 2.0 km wide, southeast-trending zone of moderately to strongly strained rocks (Figure 37.4). The DLDZ is characterized by both ductile and brittle–ductile shear zones which occur in two dominant orientations: 090° to 100°, and 110° to 120° (Figure 37.5). Shear zones at these orientations within the mafic to intermediate metavolcanic rocks are defined by 1 to 50 m of chlorite–calcite and, rarely, chlorite–iron carbonate schists. Shear zones within feldspar and quartz–feldspar–porphyry intrusions are defined by quartz–sericite schist. Narrow, northeast (060° to 070°) and northwest-trending (340°), brittle and brittle–ductile shear zones are also observed within the DLDZ (Figure 37.5). Brittle fracturing is well developed throughout the DLDZ, with the the greatest density of fracturing occurring in orientations parallel to ductile shear zones.

Foliation in rocks outside the discrete shear zones within the DLDZ is moderately to strongly developed, and in general strikes parallel to the discrete shear zones. Lineations plunge subvertically to both the northwest and southeast (Figure 37.6). Although kinematic indicators are not well developed in the DLDZ, the dominance of subvertical lineations may indicate that movement within the DLDZ occurred as dip–slip displacement. Rare shear band (C') structures observed in the western part of the DLDZ indicate that there may also have been a dextral strike–slip component of displacement.

In the northern part of Dog Lake, a 500 m wide, northeast- to east-trending zone of deformation is included as part of the DLDZ (Figure 37.4). The eastern part of this zone is defined by a well developed, northeast-trending foliation in mafic to intermediate and felsic to intermediate metavolcanics. Shear zones in this part of the deformation zone are rarely greater than 1 m in width and occur at various orientations, including 080°, 090°, 250°, 290°, and 310° (Figure 37.5). Lineations in the eastern part of the arm of deformation plunge steeply to the northeast (Figure 37.6).

The western part of this arm of deformation is much more structurally complex. Foliation is well developed, but varies in orientation with proximity to several 20 to 30 m wide shear zones at orientations of 070° and 090° (Figure 37.5). Shear folding and crenulation cleavage are well developed in this part of the deformation zone, but vary irregularly in orientation, asymmetry, and degree of plunge. Lineations within the shear zones have shallow plunges toward the southwest (Figure 37.6). This structurally complex portion of the DLDZ is poorly understood and may reflect the intersection of two or more major shear zones.

McKewen Lake Deformation Zone (MLDZ)

The McKewen Lake Deformation Zone (MLDZ) is a 1.5 km wide, southeast–trending zone of strongly deformed mafic to intermediate and felsic to intermediate metavolcanic rocks, which can be traced from McKewen Lake, in the northern part of West Township, southeastwards to the northwestern corner of Stover Township (Figure 37.4). Outcrops of the Harcourt Lake Stock mapped during the current study did not exhibit a strong strain intensity. However, the MLDZ has been shown cutting the stock (Figure 37.4), based on the presence of copper-bearing shear zones which are reported to be cutting the stock (Srivastava and Bennett 1978) at orientations subparallel to the MLDZ.

Foliation trending 110° to 120° is well developed within the MLDZ, both as a schistosity and also as a tectonic layering. Lineations within this zone plunge moderately to steeply towards the southeast, except in outcrops adjacent to the Ash Lake Pluton where lineations plunge steeply towards the northwest (Figure 37.6).

Although discrete, 120°– to 130°–trending ductile shear zones are common throughout the MLDZ, only a small number of shear zones greater than 1 m in width were observed (Figure 37.5). Kinematic indicators in those zones with northwest–plunging lineations indicate a sinistral, south–side–up sense of displacement, whereas kinematic indicators in shear zones with southeast–plunging lineations indicate a dextral, south–side–up sense of displacement. Other ductile shears within the MLDZ strike at 060° to 070° (Figure 37.5) sinistrally displacing foliation and, in some cases, southeast–trending shear zones. Although brittle fracturing is not as common as was observed in the DLDZ, the greatest density of fracturing occurs at orientations subparallel to the 060°– to 070°–striking shear zones.

Baltimore Lake Deformation Zone (BLDZ)

The Baltimore Lake Deformation Zone (BLDZ) is located in northwestern Stover Township (Figure 37.4), where it is defined by a 1.2 km wide, southeast–trending zone of folding, transposition, and shearing. The BLDZ can be traced for approximately 6 km southeastward across Stover Township (Figure 37.4). Extensions of the BLDZ to the southeast and northwest, as shown in Figure 37.4, are speculative and await verification by further detailed mapping. The BLDZ is localized within a heterolithic package of rocks which includes massive and pillowed mafic flows, felsic crystal and lapilli–tuffs and wacke–argillite metasediments (Figure 37.4). Both the felsic tuffs and the metasediments are finely bedded and, therefore, locally record much of the complex folding and shearing. The BLDZ is characterized by rootless isoclinal folds (i.e. intrafolial folds) of bedding/schistosity, sinistral and dextral shear folds, transposition, and ductile shear zones axial planar to the folds.

Lineations within the BLDZ plunge at 60° to 65° to the southeast, except in the immediate vicinity of the Rennie Lake Stock (Figures 37.4 and 37.6) where shear zones become more east–trending and lineations become steeper and eventually plunge northwest at 55°. Kinematic indicators within the BLDZ are ambiguous; however, much of the data indicates a dextral, south–side–up sense of oblique displacement.

Colborne–Stephenson Lakes Deformation Zone (CSDZ)

The Colborne–Stephenson Lakes Deformation Zone (CSDZ) is located in southern Rennie Township (Figure 37.4), where it is defined by a 300 m wide zone of ductile shearing and moderately to strongly deformed rocks. The CSDZ can be traced for at least 4 km, is open to the east, and has not been traced westward of the Rennie Lake Stock (Figure 37.4), which may truncate or deflect the zone.

The CSDZ is localized in felsic to intermediate pyroclastic rocks with minor mafic metavolcanic intercalations (Figure 37.4). Within the CSDZ there are several ductile shear zones where the rocks are deformed to sericite–chlorite–quartz±carbonate schists. These shear zones trend from 085° to 110° and range in width from less than 1 m to 10 m (Figure 37.5). Although brittle fracturing is observed in the vicinity of the CSDZ, it is poorly developed and relatively weak. Throughout most of the CSDZ, lineations plunge toward the west at 60° to 70°; however, in the Rennie Lake area, lineations steepen to 70° to the west (Figure 37.6). Kinematic indicators are poorly developed and give ambiguous senses of displacement.

Other Shear Zones

Although deformation in the Missanabie–Renabie district appears to be concentrated in deformation zones within the volcano–sedimentary rocks (Figure 37.4), evidence of deformation is also observed in the external granitoid rocks. This is best represented by the Ash Lake Pluton (ALP). Discrete ductile and brittle–ductile shear zones within faintly to weakly deformed rocks are relatively common throughout most parts of the ALP; however, collectively the deformation intensity and density of shear zones are not sufficient to define deformation zones. The discrete shear zones observed within the ALP vary in width from less than 1 cm to greater than 20 m and occur in relatively consistent orientations, including 060° to 070°, 090° to 100°, 120°, 130° to 140°, and 160° to 170° (Figure 37.6). This range of shear zone orientations is very similar to those observed within the volcano–sedimentary rocks.

Brittle fracturing is also common within the pluton and, like fracturing observed in the volcano–sedimentary rocks, occurs with greatest density in orientations subparallel to discrete shear zones. A good example of such a zone of brittle fracturing within the ALP occurs west of the community of Missanabie, where a 3 m wide zone of intense brittle fracturing, striking 100°, cuts a well developed, north–trending foliation. It is suspected that zones of fracturing such as this one, and observed elsewhere within the ALP, may change progressively along strike from brittle to ductile shear zones.

REGIONAL FOLDING

Riley (1971) and Srivastava and Bennett (1978) have defined several major east– to southeast–trending, anticlinal and synclinal fold structures within the study area. The best defined of these folds is the southeast–trending, "isoclinally folded Baltimore Lake Syncline" (Riley 1971), which is coincident with the BLDZ delineated during this study. Early regional isoclinal folding is evident in the Baltimore Lake area; however, superimposed/progressive shear folding, transposition, and ductile shearing characteristic of the BLDZ modify earlier synformal–antiformal geometries such that they may now be impossible to delineate. An anticlinal structure southwest of the "Baltimore Lake Syncline" (Riley 1971) is also coincident with a regional deformation zone—the MLDZ—which is characterized by shear folding and strong to intense ductile shearing.

Folding is evident outside the regional deformation zones and is suspected to be parasitic to regional folding; however, insufficient data exist to delineate these regional folds. Regional folding is vague within the relatively homogeneous mafic metavolcanic rocks, west of the Meath Lake Fault (Figure 37.4), due to the lack of distinctive marker horizons or bedded units.

LATE FAULTING

Two prominent fault trends, 020° to 060°, and 320° to 350°, have been defined in the area by Riley (1971) and Srivastava and Bennett (1978). The 320° to 350° group is more prevalent and best exemplified by the Meath Lake Fault (Figure 37.4). This fault is of regional extent and offsets all geological features (including major deformation zones delineated during the current study) by at least 0.8 km sinistrally (Srivastava and Bennett 1978). However, the apparent horizontal offset of the Ash Lake Pluton is closer to 4.5 km (Figure 37.4). The amount of vertical offset is not known, but the dichotomous character of the supracrustal stratigraphy and structural style across the fault suggests a significant vertical component. A parallel, northwest–trending structure referred to here as the Dog Lake Fault (Figures 37.4 and 37.5) is suspected to cause a northwest–trending foliation in the Dog Lake area outcrops (Figure 37.6), and possibly marks the eastern limit of the EBDZ (Figure 37.5). No significant displacement is documented on the Dog Lake Fault. The Maskinonge Lake Fault (Figure 37.3), in the Goudreau–Lochalsh area, is another of these northwest–trending faults.

The northwest–trending faults appear to have localized diabase dikes, as, to a lesser degree, have the northeast–trending faults. The northwest–trending faults are dominantly sinistral, while the northeast set are dextral; however, there are local exceptions to this pattern (Riley 1971; Srivastava and Bennett 1978).

KINK BANDS

Kinks bands recorded during the current study can be grouped into two sets: a northwest–trending, sinistral set and a northeast–trending, dextral set.

ALTERATION

REGIONAL METAMORPHIC GRADE

Archean volcano–sedimentary lithologies in the study area are of middle–greenschist metamorphic grade, except adjacent to the Northern Batholithic Complex and the Ash Lake Pluton, where almandine–amphibolite and hornblende–hornfels metamorphic grades are attained, respectively (Figures 37.4 and 37.7) (Riley 1971; Srivastava and Bennett 1978; Bennett 1978).

ALTERATION WITHIN THE DEFORMATION ZONES

Alteration within the deformation zones is variable, depending on the host–rock composition. The majority of the zones are characterized by the introduction of variable amounts of chlorite, calcite, minor sericite, pyrite, epidote, iron–carbonate (locally), and silica (Figure 37.7).

Chlorite, calcite, and epidote are ubiquitous in strained mafic metavolcanic rocks throughout the study area. Iron–carbonate is only found locally in individual shear zones within some of the deformation zones, such as the DLDZ or the EBDZ (Figure 37.7). Iron–carbonate is less prevalent in the MLDZ and the BLDZ, although it is locally present (Figure 37.7). Sericite, an important alteration mineral in many gold deposits elsewhere in the Archean (Colvine *et al.* 1988), is developed sporadically within the study area (Figure 37.7). In most of the localities where it is present, sericite is a product of shearing and feldspar breakdown in felsic metavolcanic rocks or feldspar–quartz–porphyry intrusions, and is not necessarily due to potassium metasomatism (i.e. potassium addition), which is a process integral to many gold deposits (Colvine *et al.* 1988). Minor potassium metasomatism is associated with some of the known gold occurrences; however, this metasomatism is on a much less extensive scale than was documented in the Goudreau–Lochalsh area to the west (Heather and Arias 1987). Pyrite is a common secondary mineral in all of the deformation zones, usually as disseminations or stringers associated with quartz veins. Locally, pyrite occurs in massive concentrations within narrow shear zones, such as those south of Loch Lomond (Occurrence 3, Figure 37.7) or at the Maisondor Occurrence (Occurrence 10, Figure 37.7).

ALTERATION OUTSIDE THE DEFORMATION ZONES

Alteration outside the deformation zones is more difficult to categorize due to the regional greenschist–grade metamorphism. Chlorite, calcite, and epidote are the most commonly observed alteration minerals; however, it is not clear in the majority of cases whether these represent early, synvolcanic alteration, greenschist metamorphism, or both. Epidote and hematite are ubiquitous throughout the Ash Lake Pluton, the Northern Batholithic Complex, and several of the internal granitoid stocks. Garnet was found in three localities (Figure 37.7): one on Colborne Lake and one on Stephenson Lake, spatially associated as halos on quartz veins within greenschist–grade, felsic to intermediate, tuffs and crystal tuffs; and one on Loch Lomond in Glasgow Township, associated with amphibolites. The first two occurrences are thought to be metasomatic in origin while the origin of the third is indeterminate.

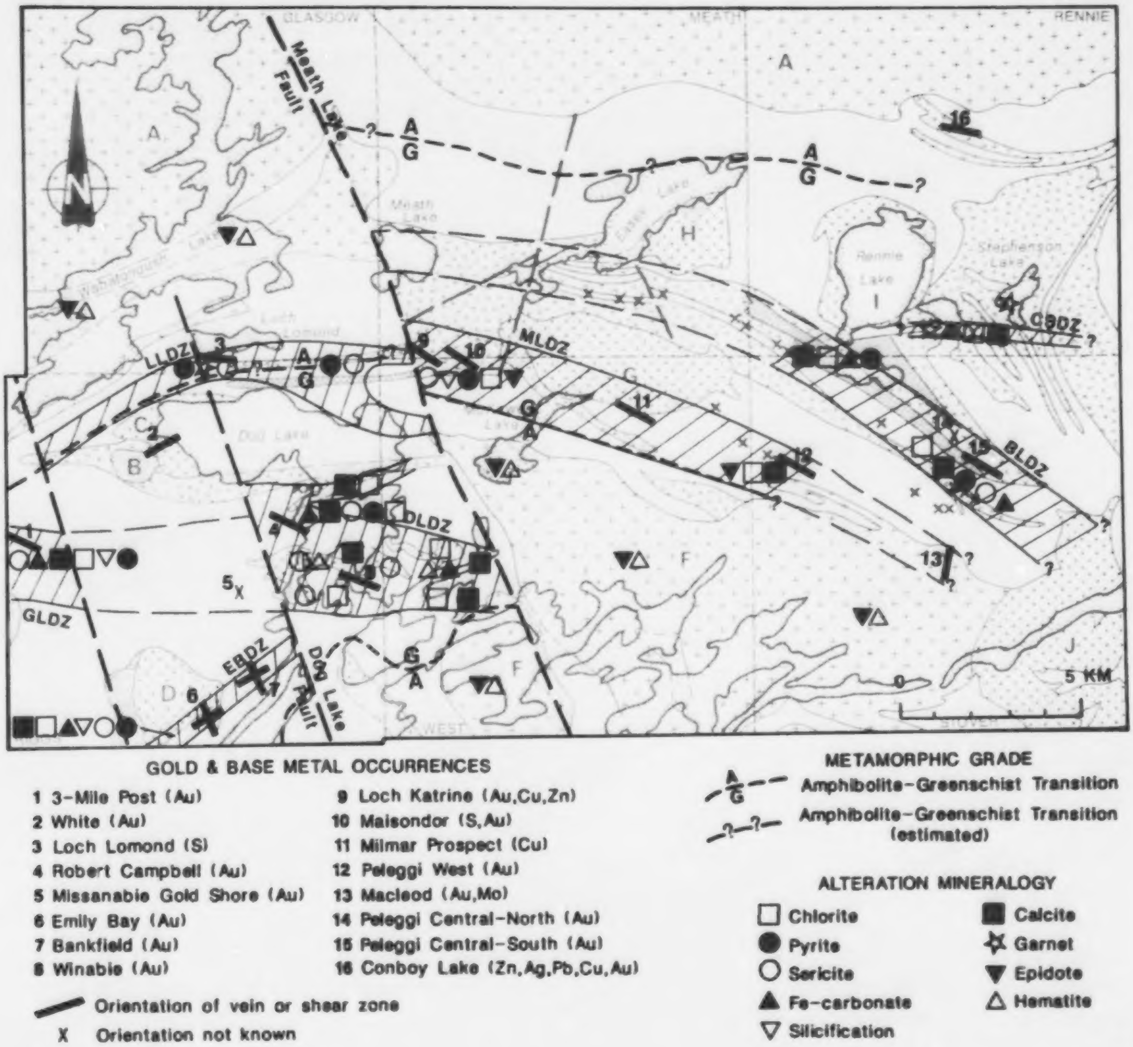
METALLOGENY

GOLD OCCURRENCES

Descriptions of many of the gold occurrences can be found in various government reports (Burwash 1935; Bruce 1942, 1948; Horwood 1942; Riley 1971; Bennett 1978; Srivastava and Bennett 1978), university theses (Kilias 1984; Callan and Spooner 1987), and government assessment files (Assessment Files Research Office, Ontario Geological Survey, Toronto).

The following summarizes the general characteristics of gold mineralization in the study area. All the gold occurrences, except the White Occurrence, are found within discrete brittle, brittle–ductile, or ductile shear zones within regional zones of deformation (Figure 37.7). Gold occurs in all rock types within the area, including the external granitoids (Occurrence 13, Figure 37.7) and a diabase dike (Occurrence 2, Figure 37.7). The majority of the occurrences are found within mafic metavolcanic rocks spacially associated with felsic feldspar–quartz porphyry dikes and/or stocks (e.g. Occurrences 1, 6, and 8, Figure 37.7). Gold is also found in sheared magnetite–bearing iron formation (e.g. Occurrence 12, Figure 37.7), intermediate to felsic pyroclastics (e.g. Occurrences 14 and 15, Figure 37.7), and is spatially related to a lamprophyre dike (e.g. Occurrences 14 and 15, Figure 37.7).

Most of the known gold occurrences are small, discontinous, single quartz veins or vein arrays hosted by discrete shear zones. There are three


GLASGOW
MEATH
RENNIE
Meath Lake Fault
A
G
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Meath Lake
Esker Lake
H
Rennie Lake
I
Stephenson Lake
16
CBDZ
LLDZ
3
Loch Lomond
9
10
MLDZ
11
12
BLDZ
14
15
13
C
2
B
Dog Lake
1
DLDZ
4
8
5X
GLDZ
EBDZ
6
7
D
Dog Lake Fault
F
J
0
5 KM
WEST
STOVER
GOLD & BASE METAL OCCURRENCES
1 3-Mile Post (Au)
2 White (Au)
3 Loch Lomond (S)
4 Robert Campbell (Au)
5 Missanabie Gold Shore (Au)
6 Emily Bay (Au)
7 Bankfield (Au)
8 Winabie (Au)
9 Loch Katrine (Au,Cu,Zn)
10 Maisondor (S,Au)
11 Milmar Prospect (Cu)
12 Peleggi West (Au)
13 Macleod (Au,Mo)
14 Peleggi Central-North (Au)
15 Peleggi Central-South (Au)
16 Conboy Lake (Zn,Ag,Pb,Cu,Au)
Orientation of vein or shear zone
X Orientation not known
METAMORPHIC GRADE
A/G Amphibolite-Greenschist Transition
-?-?- Amphibolite-Greenschist Transition (estimated)
ALTERATION MINERALOGY
□ Chlorite
● Pyrite
○ Sericite
▲ Fe-carbonate
▽ Silicification
■ Calcite
✡ Garnet
▼ Epidote
△ Hematite

Figure 37.7. *Alteration, metamorphic grade, gold and base metal occurrences, regional deformation zones and general geology in the Missanabie-Renabie district.*

dominant vein orientations: 105° to 120°, 060° to 070°, and approximately 160°. The 105° to 120° set is common within the DLDZ, BLDZ, and MLDZ, while the 060° to 070° and 160° sets are common in the EBDZ. Many of the veins observed during the study show evidence of having undergone some degree of deformation (e.g. shearing, boudinage, or transposition). In addition, multiple stages of veining are present at some of the occurrences; however, it is not known which generations are auriferous. The quartz ranges from bull-white to greyish in colour and from glassy to sugary in texture. No correlation could be made between these vein characteristics and gold tenor. Pyrite is by far the most common sulphide associated with the auriferous quartz veins, with chalcopyrite, arsenopyrite, galena, and sphalerite being far less common. The alteration type found adjacent to, and in the vicinity of, many of the auriferous veins consists of variable amounts of chlorite, iron-carbonate, sericite, pyrite, calcite, and quartz. The extent of hydrothermal alteration around many of the vein systems is limited to several metres and rarely extends to tens of metres. Extensive potassium metasomatism is not found at any of the gold occurrences shown on Figure 37.7.

All the gold occurrences in the area are thought to be of Archean age except the White Occurrence, which is hosted by 060°–trending quartz veins that occupy brittle fractures within both the potassium feldspar megacrystic Lochalsh Bay Stock and a 340°–trending diabase dike. Gold mineralization is confined to that portion of the quartz–fluorite–magnetite–pyrite vein system occurring within the diabase dike (Srivastava and Bennett 1978). The mineralization is spatially and possibly genetically related to the nearby, Proterozoic–aged Manitou Mountain olivine gabbro stock (Figures 37.4 and 37.7).

BASE METAL MASSIVE SULPHIDE MINERALIZATION

The Conboy Lake zinc–silver–(lead–copper–gold) occurrence is the only significant surface showing of base metals in the Missanabie–Renabie district (Figure 37.6). The genetic origin of this deposit is equivocal, as it has characteristics of volcanogenic massive sulphide mineralization but also lies within intensely "sheared sericitic metatuff" (Riley 1971). The orientation of the Conboy Lake Occurrence is 110° to 120° which is identical to the orientation of the majority of gold occurrences (Figure 37.7). Pyrite–pyrrhotite sulphide occurrences are found in the area associated with iron formation or shear zones.

DISCUSSION

Of the six major deformation zones outlined in the Missanabie–Renabie district during this study, four (DLDZ, EBDZ, MLDZ, and BLDZ) host all of the known gold occurrences. The remaining two deformation zones (LLDZ and CSDZ) have structural and alteration characteristics similar to the gold bearing ones and hence are favourable exploration targets. The DLDZ is characterized by the presence of both ductile and brittle–ductile shearing trending between 090° and 120°, as well as a large degree of brittle fracturing. Similar features are documented immediately to the west, within the eastern domain of the Goudreau Lake Deformation Zone (Arias and Heather 1987; Heather and Arias 1987). Therefore, the DLDZ may represent an eastward extension of the Goudreau Lake Deformation Zone (Figure 37.3). Furthermore, the following observations indicate that the MLDZ may be an eastward extension of the DLDZ, despite being separated and sinistrally offset by the Meath Lake Fault (Figures 37.3 and 37.4):

1. Similar intrusions of feldspar and feldspar–quartz porphyry are found in the eastern portion of the DLDZ and in the western portion of the MLDZ.
2. West–plunging lineations are found in the eastern portion of the DLDZ and in the western portion of the MLDZ (Figure 37.6).
3. The northern margin of the Ash Lake Pluton is offset sinistrally from south of the DLDZ to south of the MLDZ (Figure 37.4).

Although the MLDZ has a more ductile structural style than the DLDZ, this difference could be explained by an unknown amount of vertical displacement along the Meath Lake Fault. Vertical displacement along the Meath Lake Fault may also account for the distinct change from a massive, mafic metavolcanic–dominated stratigraphy west of the fault to a diverse, metavolcanic–metasedimentary stratigraphy east of the fault (Figure 37.4).

The locations of the MLDZ and BLDZ, as outlined during the current study, are coincident with regional fold traces interpreted by earlier mappers (Riley 1971; Srivastava and Bennett 1978). At an outcrop scale, small–scale folds, possibly parasitic to larger folds, are cut and transposed by shearing parallel to their axial traces. This relationship indicates that folding and shearing may be related and may have been produced during progressive deformation.

Other regional structures within the Missanabie–Renabie district include northwest–trending structures similar to the Meath Lake Fault (Figure 37.5) and northeast–trending structures, interpreted by earlier mappers (Riley 1971; Srivastava and Bennett 1978), that may be related to similarily oriented deformation zones, such as the EBDZ and the northern arm of the DLDZ (Figure 37.5). Although the temporal relationships between these structures are not clearly understood, field observations suggest that the 060°–trending EBDZ is truncated by an interpreted, 340°–trending structure, referred to here as the Dog Lake Fault (Figure 37.5). This suggests that the northwest structures postdate the northeast structures. Timing relationships between the 060°–trending structures and the other major deformation zones are not clear.

ECONOMIC POTENTIAL

Potential for volcanogenic massive sulphide mineralization is low; however, the origin of the Conboy Lake base metal occurrence is ambiguous at present and this occurrence may represent synvolcanic mineralization.

All the known gold occurrences consist of quartz vein systems hosted by narrow ductile, brittle–ductile, and brittle shear zones within regional zones of deformation. Favourable alteration consists of sericite, iron–carbonate, calcite, sulphides, and chlorite within any of the rock types in the area. All of the deformation zones delineated during this study are favourable exploration targets, especially extensions of these zones into areas where the access is poor, or the glacial cover is thick, or there are no known gold occurrences.

The Renabie Gold Mine is hosted by quartz veins within a brittle–ductile shear zone in the external granitoids. Therefore, exploring and prospecting are warranted in areas where the regional deformation zones or discrete shear zones occur in either external or internal granitoids.

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38. Project Number 88–20. Digital Integration of Remote–Sensing Data into a Geoscience Data Base for the Goudreau–Lochalsh Study Area, Michipicoten Greenstone Belt

R.S. Mussakowski[1] **and N.F. Trowell**[2]

[1]Staff Scientist, Ontario Centre for Remote Sensing, Surveys, Mapping and Remote Sensing Branch, Ministry of Natural Resources, Toronto.

[2]Geoscientist, Ontario Geological Survey, Ministry of Northern Development and Mines, Toronto.

INTRODUCTION

In 1987, the Ontario Geological Survey (OGS) and the Ontario Centre for Remote Sensing (OCRS) jointly initiated a multidisciplinary study to evaluate the digital integration of remote sensing into geoscience data bases. The area chosen for the study was the Goudreau–Lochalsh site, located within the Michipicoten Greenstone Belt approximately 40 km northeast of Wawa (Figure 38.1). The study area is underlain predominantly by supracrustal metavolcanic and metasedimentary rocks bounded to the north by granitoid rocks. The site is accessed from Wawa by Highway 17, Highway 519, and then a network of logging roads within the area.

The ready availability of data on the site was one reason for its selection. A high–quality geological data base was immediately available (Sage 1985), and mapping was currently underway in the area (Sage 1987; Arias and Heather 1987; Heather and Arias 1987; Fortescue and Stahl 1987). The release of two other data sets was also imminent: digital geophysical data (Barlow 1987, in preparation) and airborne radar data (from the Radar Data Development Program of the Canada Centre for Remote Sensing, Department of Energy, Mines, and Resources Canada). A second reason for choosing the site was its high mineral potential. Intensive exploration and mine development are already underway in the area (Heather, Arias, and Reilly 1988; Heather, Arias, and Sage 1988).

GEOLOGY OF THE STUDY AREA

The area is predominantly underlain by pillowed, massive and schistose, intermediate to mafic metavolcanics, with minor intercalated mafic pyroclastics. The northern edge of a major felsic to intermediate metavolcanic sequence is exposed along the southern portion of the area. Along the northern margin of the supracrustal sequence, a unit of thin bedded wackes and siltstones with an ironstone horizon separates the metavolcanics from the external grani-

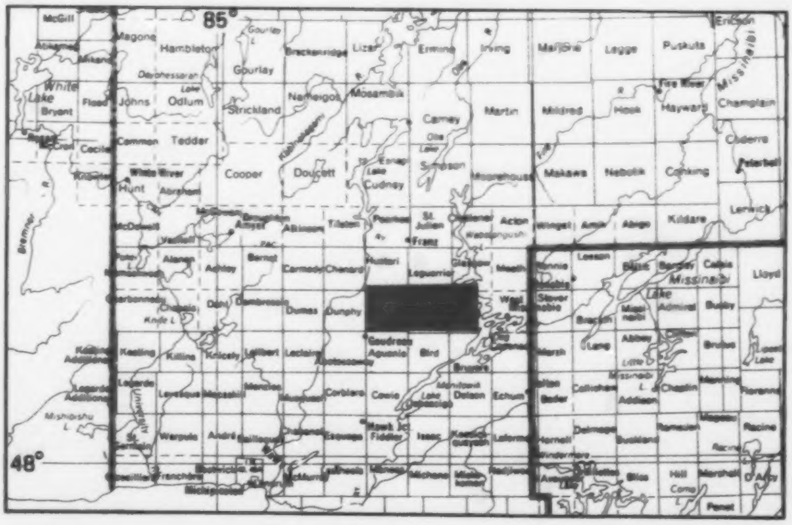
85°
48°
McGill
Magone
Hambleton
Gourlay
Brackenridge
Lizar
Ermine
Irving
Legge
Puskuta
Ericson
Missinaibi
White Lake
Bryant
Flood
Johns
Odlum
Strickland
Nameigos
Mosambik
Carney
Martin
Mildred
Hook
Hayward
Champlain
Common
Tedder
Cecile
Chewett
Peterbell
White River
Hunt
Abraham
Cooper
Doucett
Cudney
Simpson
Moorehouse
Makawa
Nebotik
Cohoring
Lerwick
McDowell
Amyot
Albinson
Tilston
St. Julien
Franz
Acton
Kildare
Alanen
Ashley
Bernst
Carmody
Chenard
Hunter
Lepurrier
Lessard
Missinaibi Lake
Lloyd
Charbonneau
Daly
Dumas
Dunphy
Knife L.
Goudreau
Aguonie
Bird
Keating
Killins
Lalibert
Leclair
Abbey
Lang
Little
Missinaibi L.
Chaplin
Bruce
Legarde
Laveque
Corbiere
Cowie
Lake
Dolson
Echum
Callahan
Addison
Mishibishu L.
Warpula
Andre
Esquega
Hawk Jct.
Fiddler
Isaac
Kenogami
Racine
Hill
Marshall
D'Arcy
McMurray
Michano
Bliss
Pernet

Figure 38.1. *Location map for the Goudreau–Lochalsh Study area, District of Algoma. Scale 1:1 584 000 or 1 inch to 25 miles.*

toids. There is also minor iron formation along a portion of the mafic–felsic metavolcanic contact in the southern part of the area. Several mafic intrusions, likely coeval with the mafic volcanism, intrude the intermediate to mafic metavolcanics. The Herman Lake Nepheline Syenite and Maskinonge Lake Granitic Stock intrude the supracrustal sequence. Diabase dikes crosscut the supracrustal sequence and bounding granitoids.

The area has a complex structural history which has been studied and documented in some detail (Arias and Heather 1987; Heather and Arias 1987). Remote-sensing data is expected to contribute to the interpretation of the local structural geology and, in the future, to the interpretation of the entire Michipicoten and Mishibishu Lake greenstone belts.

PREPARATION OF DATA SETS AND DIGITAL IMAGE PROCESSING

Remote sensing has been increasingly used as a standard tool in geoscience interpretation. Satellite imagery, in particular, has been recognized as a valuable aid in regional structural mapping (Watson 1985). High-resolution satellite data, such as LANDSAT 5 data (with a resolution of 28 m) and SPOT data (with resolutions of 10 m and 20 m) as well as airborne radar data, do, however, demonstrate potential for more detailed interpretation and mapping.

Satellite and airborne-radar data are digitally recorded and, therefore, are amenable to computer analysis. Specialized computerized systems which permit the display, classification, and enhancement of remote-sensing data are called image-analysis systems. These systems can also be used for the analysis of non-image data such as digitally recorded aeromagnetics. Geological maps can be manually or automatically digitized and manipulated by the system.

With a common geographic-reference base, these digital-data sets can be integrated. Data integration allows the geologist to apply conventional interpretive techniques over various data sets which can be physically viewed, superimposed, or merged. Various processing techniques can be used to enhance specific features.

The following five digital-data sets have been created for the Goudreau–Lochalsh study area:

1. LANDSAT 5 Thematic Mapper data recorded on October 15, 1985
2. airborne radar (SAR) data recorded by the Data Acquisition Division of the Canada Centre for Remote Sensing (CCRS)
3. total field aeromagnetic data derived from digital archives of the Ontario Geological Survey
4. general geology (mapped by R.P. Sage, Geologist, Precambrian Geology Section, Ontario Geological Survey)
5. surficial geology (preliminary interpretation by F. Kenny of OCRS)

The following four merged data sets have been created and were either plotted at various scales, using a colour ink-jet plotter, or transcribed onto film:

1. LANDSAT and airborne SAR data at a scale of 1:25 000
2. airborne SAR data and aeromagnetic data at a scale of 1:25 000
3. general geology maps and airborne SAR data at a scale of 1:25 000
4. first-derivative aeromagnetic data and airborne SAR data

From the integrated data, any combination among the data sets can be interactively created and plotted at any scale. Photo 38.1 is a black and white representation of a merged data set. When data sets are merged, each can still be read through the other(s).

ASSESSMENT OF REMOTE-SENSING DATA AND DATA INTEGRATION

LANDSAT and airborne SAR data were first evaluated for their ability to contribute to existing knowledge of the study area. Since the area had been intensively mapped from field investigation (Sage 1985, 1987; Arias and Heather 1987; Heather and Arias 1987) prior to the interpretation of the remote-sensing data, only a few new geological features were detected. It is a common difficulty in the assessment of remote-sensing data that when new features interpreted from the data are checked in the field, no distinct surface evidence may be identified from the ground perspective to support the interpretation. Such was the case in this study. In areas where outcrops occurred, however, field-mapped features did concur with the interpreted features. Furthermore, a few aeromagnetic features supported the results of remote-sensing interpretation. Photo 38.2 shows a few preliminary interpretations obtained from the remote sensing data, aeromagnetic data, and field observations.

Table 38.1 indicates on which data set the features were observed.

Feature A (Photo 38.2) is a 'strong' lineament (northeast trending) on the Radar (and Radar + Landsat) imagery; offset of the magnetic contours on the aeromagnetic-survey map (OGS 1987). There is a strong suggestion of left-lateral offset of the metasedimentary sequence. This feature was not noted during field mapping and its significance has yet to be geologically evaluated.

Feature B (Photo 38.1) is a possible easterly extension of the Maskinonge Lake Granitic Stock as

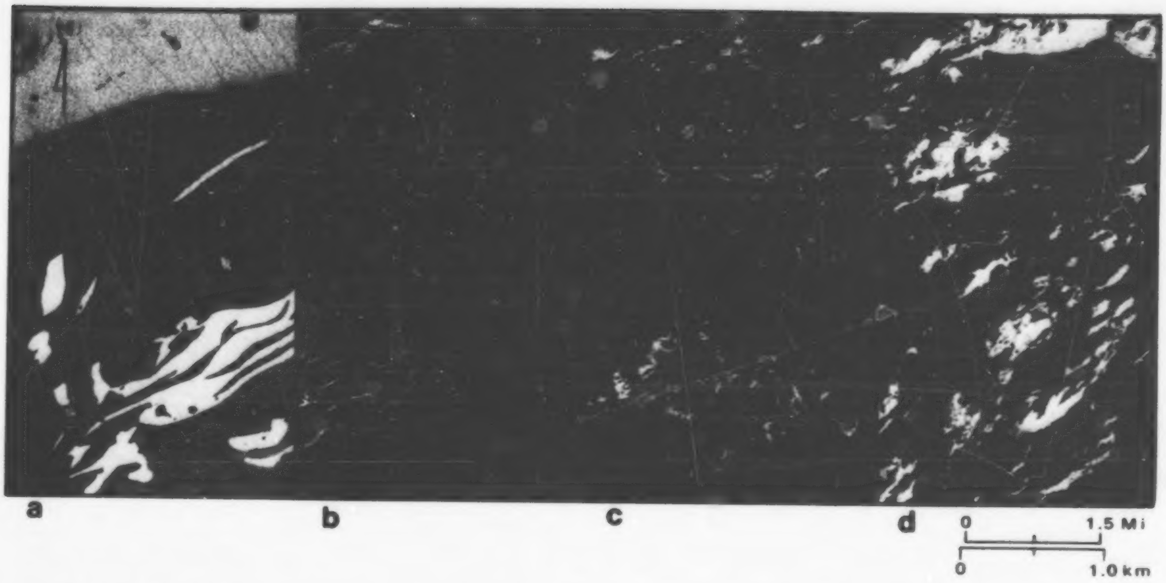

Photo 38.1. *Mosaic of the Gondreau-Lochalsh study area panels comprising from left to right (west to east): 1. Digitized geology, 2. Radar Imagery, 3. Radar and Aeromagnetic Integrated Imagery, 4. Landsat (Thematic Mapper) Imagery.*

indicated by the 'texture' on the Radar (and Radar + Landsat) imagery. Evidence on the aeromagnetic map (OGS 1987) is equivocal. This postulated interpretation was 'ground truthed' in the summer of 1988 (R.P. Sage, Geologist, Precambrian Geology Section, Ontario Geological Survey, personal communication, 1988).

> "**Problem**
>
> Radar + Landsat imagery suggested the possibility that the contact of the Maskinonge Lake Granitic Stock extended some distance east of the Maskinonge Lake Fault.
>
> **Method of Attack**
>
> Two one-way-traverse lines were run eastward from a series of swamps located near the Maskinonge Lake Fault to the Goudreau-Lochalsh access road.
>
> **Results**
>
> The two lines involved nearly 20 000 feet of traverse and resulted in a total of seven outcrops being observed. All outcrops were external to the Radar + Landsat inferred contact and are composed of supracrustal or related rocks.
>
> The Radar + Landsat inferred contact marks a break between deciduous and coniferous trees and a transition between well drained and more poorly drained topography. The recently released airborne geophysical survey map does not offer conclusive proof for the extension of the contact beyond its present interpreted limits.
>
> **Conclusion**
>
> Ground checking has failed to extend the Maskinonge Lake Granitic Stock contact farther eastward on the basis of outcrop data. The curvilinear pattern displayed on Radar + Landsat imagery reflects a transition from a dominantly deciduous to coniferous forest cover. This in turn reflects soil conditions more likely those of glacial than of bedrock origin. Radar and Landsat imagery reflect surface phenomena requiring ground checking to establish any correlation between surface and bedrock. In areas of extensive glacial cover, surface phenomena may mask underlying bedrock structures."

The final interpretation is still geologically inconclusive.

Feature C (Photo 38.2) is a north- to north-northeast-trending lineament (plus splays) that is apparent on the Radar (and Radar + Landsat) imagery. There is some indication of portions of the feature on the aeromagnetic-survey map (OGS 1987) but evidence is generally inconclusive. The feature was not noted entirely during field mapping and has yet to be geologically evaluated.

The general conclusion reached was that digital data integration techniques served to make the interpretation process easier.

Planned Continuation of the Project

The results obtained to date indicate that remote-sensing data can provide valuable new geological information. To fully demonstrate its effectiveness, however, the data should be acquired and interpreted before comprehensive field investigation is carried out. The data for the Goudreau-Lochalsh area was acquired after field investigation had been completed, so it did not contribute significantly to existing knowledge of the site.

New airborne radar and LANDSAT data were acquired during the 1988 field season. This coverage includes the entire Wawa Greenstone Belt from Pukaskwa on Lake Superior to Missinaibi Lake. Data integration similar to that completed for the Goudreau-Lochalsh site will be undertaken for all of the new area, and the site will be incorporated into the Ontario Geological Survey's schedule of current mapping activities.

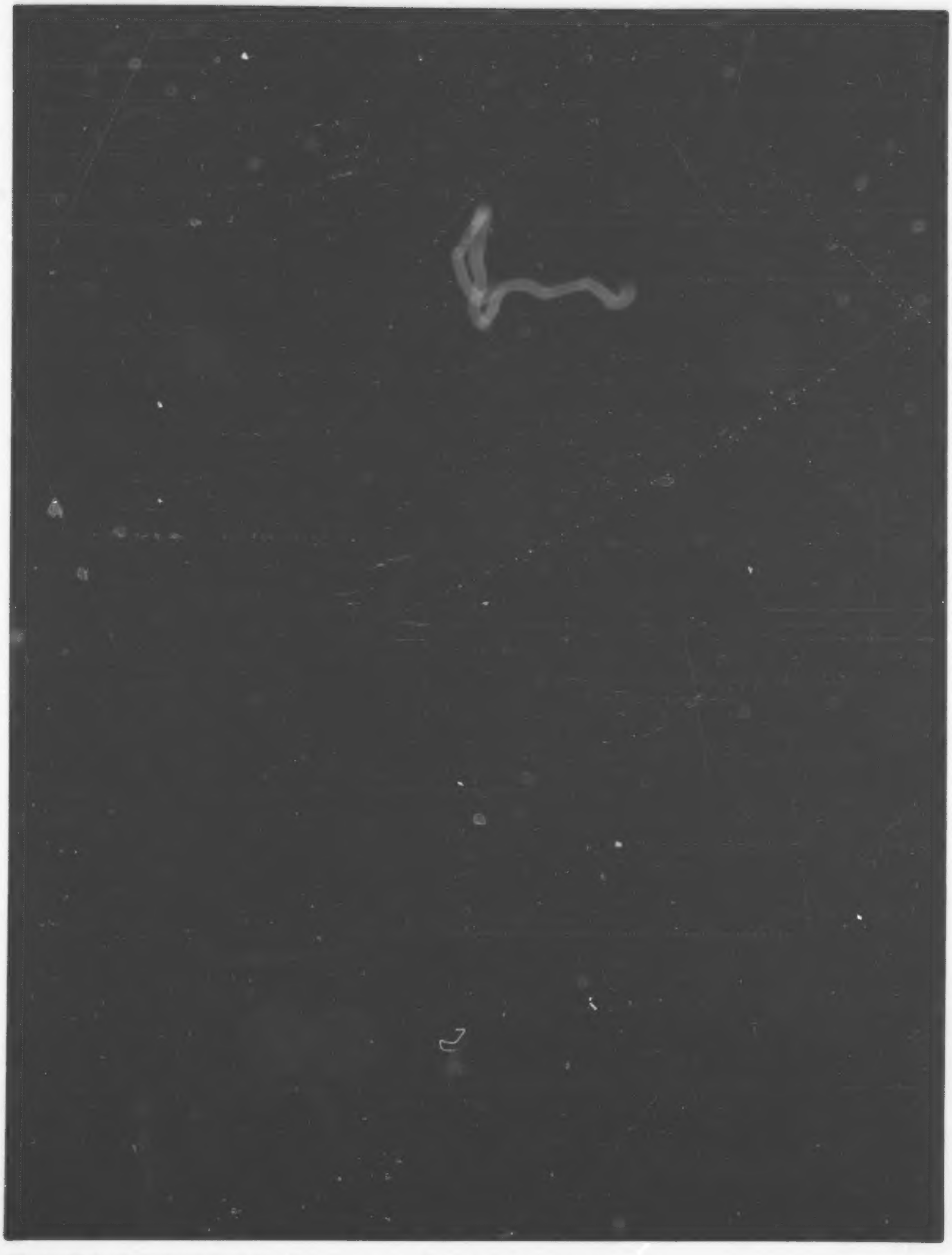

Photo 38.2. *Preliminary geological interpretation of the study area from radar data.*

TABLE 38.1: TABULATION OF FEATURES FROM PHOTO 38.2.

			Radar
Features	**Geology**	**Aeromagnetic**	**Radar + Radar Landsat**
A	-	X	X
B	-	?	X
C	-	?	X

X *Observed*
- *Not observed*
? *Uncertain*

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Proterozoic

39. Proterozoic Geology Studies, Southern and Grenville Provinces

R.M. Easton

Geologist, Precambrian Geology Section, Ontario Geological Survey, Toronto.

INTRODUCTION

Proterozoic rocks underlie fifteen percent of the Province of Ontario, and have long contributed to the mineral wealth of the Province, most notably uranium from the Huronian Supergroup, cobalt in association with the Nipissing Intrusions, nickel from the Sudbury Structure, and a variety of metallic– and nonmetallic–mineral deposits from the Grenville Province. Despite many years of study there are still large tracts of Ontario underlain by Proterozoic rocks which have not been mapped in detail or extensively prospected, or both. The goal of the Proterozoic Working Group of the Ontario Geological Survey is to improve both mapping coverage of Proterozoic terranes in Ontario and our understanding of the mineral deposits associated with these terranes.

SOUTHERN PROVINCE

Most of the 1988 field program in the Southern Province focused on the study of the Huronian Supergroup in the Cobalt Plate, and was funded under the Canada–Ontario Mineral Development Agreement (COMDA) which concludes in 1989.

Born (this volume) continued detailed mapping in the area southwest of the town of Cobalt. This area is underlain by Archean metavolcanic and plutonic rocks overlain by the Proterozoic Gowganda Formation, with Nipissing Intrusions injected along the unconformity and into the overlying Gowganda Formation. Potential mineralization in both the Archean and Proterozoic rocks is discussed in his report. Rice (this volume) completed the final year of a three–year project to investigate the sedimentology of the Huronian Lorrain Formation, begun with the intent of evaluating the paleoplacer–gold potential of the formation. Sedimentary textures present within the Lorrain Formation are for the most part equivocal with respect to depositional setting for the Lorrain Formation; however, the present consensus is that the Lorrain Formation in the Cobalt Plate was deposited in a shallow–marine rather than in a fluvial setting.

Avermann and Mueller–Mohr (this volume) report on an ongoing study of the breccias of the Sudbury Structure, this year focusing on the Sudbury breccias and the Onaping Formation. Their study is the result of a co–operative project between the Ontario Geological Survey and the University of Muenster, West Germany and forms part of the requirements for Ph.D. theses.

We are currently re–evaluating our mapping program in the Southern Province in order to determine which areas should receive priority over the next several years.

GRENVILLE PROVINCE

Many of Ontario's first mines were located in the Grenville Province, and in the past few years, a resurgence of exploration activity has occurred in the Grenville, particularly for gold, and for a variety of industrial minerals such as graphite, talc, and wollastonite. However, although easily accessible, much of the Grenville Province has not undergone detailed mapping (scales of 1:50 000 or less). To assist metallic– and nonmetallic–mineral exploration in the Grenville Province, the Ontario Geological Survey's program is threefold: a) it involves detailed mapping at 1:15 840 scale in selected areas, with priority given to areas of greatest mineral potential or exploration interest; b) production of 1:50 000 scale compilation maps, particularly in the Central Metasedimentary Belt; and c) detailed studies to address specific problems and to improve our knowledge of mineral deposits within the Grenville Province. Over the next few years, emphasis will be given to the preparation of 1:50 000 scale compilation maps for the Bancroft, Elzevir, and Sharbot Lake Terranes of the Central Metasedimentary Belt; preparation of 1:250 000 scale compilation maps for the entire Grenville Province in Ontario; a review of lithostratigraphic nomenclature and a compilation of geochemical data in preparation of the Geology of Ontario volume; and continuing studies on the geological setting and genesis of Grenville Province metallic– and nonmetallic–mineral deposits with the goal of developing improved exploration models.

The 1988 mapping program included projects of all three types. As part of the Geology of Ontario program and related map compilation projects, Easton (this volume) undertook a number of directed studies within the Grenville Province. These included an attempt to delineate lithotectonic domains in the North Bay area; additional studies to trace the extent of the Robertson Lake Mylonite Zone (RLMZ), a major geologic feature in southeastern Ontario that hosts several gold prospects; and studies of the Frontenac/Sharbot Lake Terrane Boundary which had not been previously studied in detail. This work has lead to the recognition that additional, hitherto unexplored, settings exist for gold mineralization in the Central Metasedimentary Belt, and to the discovery of a diopside occurrence along Highway 7 that may have industrial mineral applications. Further work along the RLMZ ties in with the unconformity study of DiPrisco (this volume) in that post–Grenville weathering may have locally concentrated gold along the RLMZ. In fact, the synergism of the various field programs was a common theme throughout the 1988 season, and highlights the fact that small, apparently unrelated projects can contribute to a better understanding of the geological framework and mineral potential of the Grenville Province.

Much of the 1988 field program in the Grenville was funded by the Canada–Ontario Mineral Development Agreement (COMDA). Because little detailed mapping is available for the Central Gneiss Belt, a three–year bedrock geology mapping project (1:15 840 scale) was begun in 1986 in the Parry Sound region. This work continued in 1988, and was extended south into the main part of the Parry Sound Domain. As reported by McRoberts *et al.* (this volume), rocks in this area are less deformed in relative terms than those mapped to the north in 1986–1987 (Bright 1987; McRoberts and Tremblay 1988), and, consequently, the dominantly metaigneous nature of this region has been confirmed. It also appears that the domain consists of two halves: a mafic metaigneous and metasedimentary western half, and a mainly metadioritic eastern half. The reason for this lithological distinction is not yet understood, but obviously has a bearing on the type of mineral exploration programs conducted in the Parry Sound Domain. Macfie (this volume) who served as senior assistant on the Parry Sound Project, has undertaken a thesis project at Queen's University examining the nature of the lithotectonic terrane boundaries in the western Central Gneiss Belt. The preliminary results of this study, which compliments the work of McRoberts *et al.* (this volume), indicates that domain boundaries are not always characterized by the presence of major tectonite zones, particularly when examined at detailed map scales. In conjunction with bedrock mapping of the Parry Sound Region, Chris Marmont, working out of the Dorset Resident Geologist's Office, has been investigating the industrial–mineral potential of the Parry Sound region, including, but not restricted to, the areas mapped in detail by Bright (1987), McRoberts and Tremblay (1988), and McRoberts *et al.* (this volume). Marmont (this volume) reports on his 1988 field work which elaborates upon some of his preliminary work (Marmont 1988a, 1988b; Marmont and Johnston 1987) on the mineral potential of anorthosite, feldspar, and building stone in the Parry Sound region. Tremblay (this volume) performed a lineament analysis of remote–sensing data for the Parry Sound region. Although in a broad sense, the remote–sensing data could be correlated with the regional geology, interpretation was more difficult at finer scales (less than 1:250 000), and, other than for reconnaissance investigations, use of remote–sensing data for this part of the Grenville Province has limited application. Tremblay's analysis did confirm the apparent absence of a major tectonic zone in the area studied by Macfie (this volume).

Di Prisco (this volume) continued his study of the Precambrian—Paleozoic unconformity in southern Ontario. Many historic mineral occurrences, particularly hematite producers, are related to weathering at this unconformity, which has also caused local supergene enrichment of Precambrian mineral deposits. This is applicable to mineral exploration programs and to the interpretation of soil geochemical anomalies. Springer (this volume) studied Precambrian—Paleozoic fault systems in the city of North Bay area which are locally hematized. This work is broadly related to DiPrisco's study.

In addition to the work done out of the Toronto office of the Ontario Geological Survey, the Resident Geologist's and Mineral Specialist's offices of the Ministry of Northern Development and Mines in southern Ontario have also contributed to the 1988 field program in the Grenville Province, particularly with respect to the examination of industrial minerals in the Central Metasedimentary Belt. From the Bancroft Mineral Specialist's Office, Hans Meyn (this volume) continued his study of the sedimentology of carbonate and intercalated rocks in the Madoc area. This work is part of a long–term study to understand the depositional and mineralization environments of carbonate rocks in the Central Metasedimentary Belt. Goad (this volume), also of the Bancroft Mineral Specialist's Office, continued work on a Canada–Ontario Mineral Development Agreement (COMDA) funded–project studying the pegmatites in the Central Metasedimentary Belt and the Central Gneiss Belt. Although in general the pegmatites are not favourable targets for rare–element mineralization, the pegmatites locally may be of value as sources of feldspar and quartz.

Three Canada–Ontario Mineral Development Agreement (COMDA) Projects were conducted out of the Tweed Resident Geologist's Office. Lebaron (this volume) continued his study of talc–bearing rocks in the Tudor Formation. Black and MacKinnon (this volume) examined major graphite occurrences in the Frontenac Terrane. Thompson and Williams (this volume) continued their study of the structural geology of the Madoc fluorite area. Grant (this volume), of the Drill Core Library in the town of Bancroft, which is administered from the Tweed Resident Geologist's Office, produced a geological map of Egan Chutes Provincial Park, which will be of interest to mineral collectors and the general public.

Although extremely varied in nature, the Grenville mapping projects in 1988 have led to a much better understanding of the geological framework and geological history of parts of the Grenville Province, and have enhanced our knowledge of metallic and nonmetallic mineralization in the Central Metasedimentary Belt. The results of this work will assist in preparation of a synthesis of the geology of the Grenville Province which will be beneficial to both the academic and the explorationist.

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40. Project Number 88-12. Geology of the Bay Lake Area, District of Timiskaming

P. Born[1] **and M.W. Hitch**[2]

[1]Geologist, Precambrian Geology Section, Ontario Geological Survey, Toronto.

[2]Graduate Student, Ottawa-Carleton Geoscience Centre, University of Ottawa, Ottawa, Ontario.

INTRODUCTION

The map area (240 km²) consists of the western part of Coleman Township and most of the southern two-thirds of Gillies Limit Township (Figure 40.1). It is located in the District of Timiskaming some 8 km southwest of Cobalt, 20 km north of Temagami, and 120 km north of North Bay, and bounded by Latitudes 47°13′00″N and 47°23′00″N, and Longitudes 79°55′00″W and 79°38′00″W.

Excellent access was provided by Highway 11 and a series of connected secondary lumber roads, and by Bay Lake and the Montreal River. Entry by float-plane into Island, Second Justin, Coleman, Hound Chute, and Roosevelt lakes provided water access to the remainder of the area.

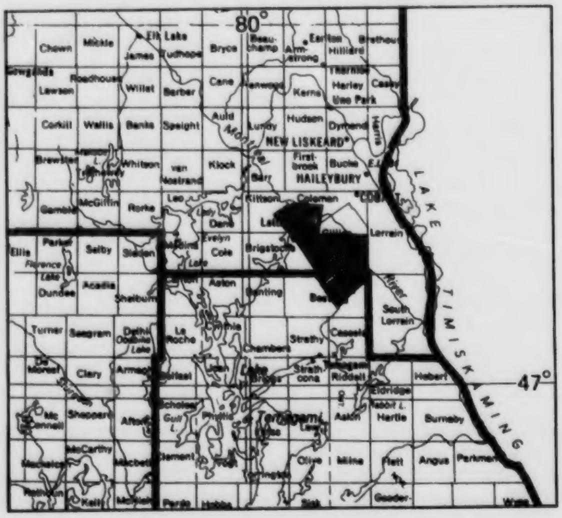
80°
47°
Chown
Mickle
Elk Lake
James
Tudhope
Bryce
Beau-champ
Arm-strong
Earlton
Hilliard
Brethour
Lawson
Roadhouse
Willet
Barber
Cane
Kerns
Harley
Casey
Corkill
Wallis
Banks
Speight
Auld
Lundy
Hudson
Dymond
Harris
NEW LISKEARD
Brewster
Whitson
van Nostrand
Klock
Barr
Firstbrook
Bucke
HAILEYBURY
Gamble
McGiffin
Leo
Kittson
Coleman
COBALT
Lorrain
Ellis
Parker
Selby
Evelyn
Cole
Brigstocke
Florence Lake
Acadia
Dundee
Aston
Banting
South Lorrain
Turner
Seagram
La Roche
Strathy
Chambers
Clary
Strath-cona
Riddell
Hebert
Eldridge
McConnell
Shepherd
Afton
Gull L.
Aston
Hartle
Burnaby
McCarthy
Olive
Milne
Flett
Angus
Parkman
Kelly
Hobbs
Gooder-
LAKE TIMISKAMING
River

Figure 40.1. *Location map of the Bay Lake area, District of Timiskaming. Scale 1:1 584 000 or 1 inch to 25 miles.*

The study area is underlain by Proterozoic metasedimentary rocks of the Cobalt Group of the Huronian Supergroup. Archean plutonic and metavolcanic rocks are exposed as relatively small inliers. Copper, cobalt, silver, and gold mineralization is known to occur in the area of investigation.

MINERAL EXPLORATION

Local silver and cobalt exploration began following the discovery of silver in the Cobalt area in 1904. The Bay Lake map area is located some 8 km to the south of the town of Cobalt.

Over fifty companies and individuals have carried out extensive mineral exploration in the map area between 1906 and 1983. This work has included the sinking of 16 shafts with approximately 900 m of underground development; the completion of approximately 22 000 m of diamond drilling in 245 holes; and the blasting of numerous trenches and test pits on mineralized surface showings. A list of previous exploration work is too lengthy for this report but will be included in the marginal notes of preliminary maps resulting from the study of the area.

GENERAL GEOLOGY

The earliest geological mapping in the area was done on a reconnaissance scale by Barlow (1899), DeLury (1913), Miller (1913), and Todd (1926). Subsequent and more detailed mapping in adjacent areas to the north of the Bay Lake area was done by Thomson (1963a, 1963b, 1963c) and Johns (1985). Lorrain Township to the east was mapped by Lovell and de Grijs (1978). Banting and Best townships to the west were mapped by Smyk and Oswiacki (1986). Born and Burbidge (1987) surveyed adjacent Brigstocke and Kittson townships.

Underlying the map area are Archean supracrustal and plutonic rocks, Early Proterozoic supracrustal and intrusive rocks, and Middle Proterozoic diabase and lamprophyre dikes (Figure 40.2).

CANADA ONTARIO

This project A.4.3 is part of the five year Canada-Ontario 1985 Mineral Development Agreement (COMDA), a subsidiary agreement to the Economic and Regional Development Agreement (ERDA) signed by the governments of Canada and Ontario.

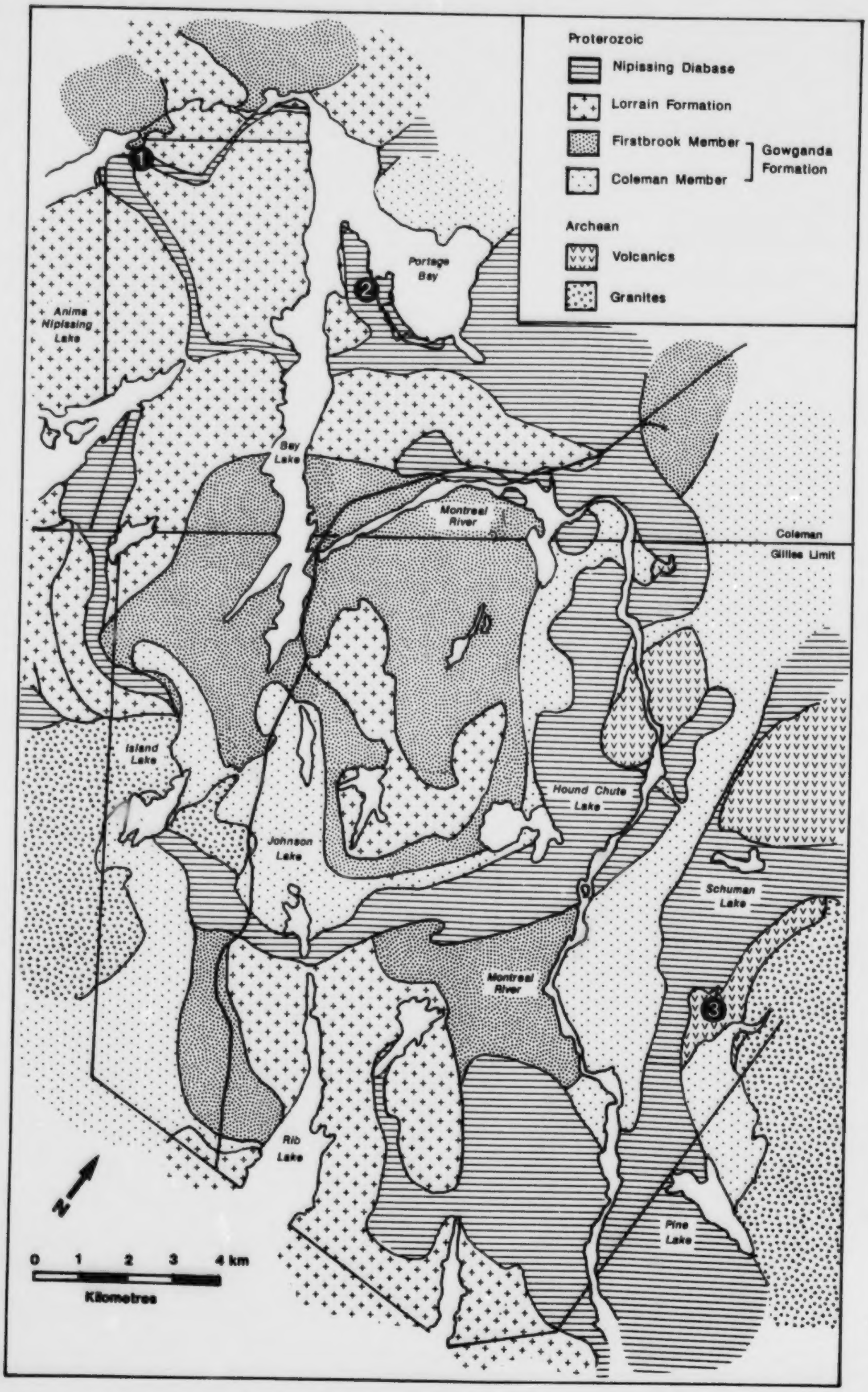
Proterozoic
Nipissing Diabase
Lorrain Formation
Firstbrook Member
Coleman Member
Gowganda Formation
Archean
Volcanics
Granites
1
Portage Bay
2
Anima Nipissing Lake
Bay Lake
Montreal River
Coleman
Gillies Limit
Island Lake
Hound Chute Lake
Johnson Lake
Schuman Lake
Montreal River
3
Rib Lake
N
0 1 2 3 4 km
Kilometres
Pine Lake

Figure 40.2. *General Geology of the Bay Lake Area, District of Timiskaming. Properties: (1) Shakt–Davis Mine; (2) Portage Bay Occurrence; (3) Borden Lake Occurrence.*

ARCHEAN ROCKS

Archean rocks underlie the southwestern and northeastern parts of the map area, and consist mainly of felsic plutonic and migmatitic rocks with lesser amounts of mafic metavolcanics.

Mafic metavolcanic rocks occur as two distinct types. The first type is characterized by fine- to medium-grained amphibolites which exhibit varying degrees of migmatization including agmatic (breccia), phlebitic (vein), and ptygmatic structures (Mehnert 1971). Similar rocks have been described in areas to the west of the study area by Smyk and Oswiacki (1986) and by Born and Burbidge (1987). The amphibolites occur in the southwestern part of the study area as volcanic enclaves within felsic plutonic rocks. The second type are well-preserved, greenschist-facies mafic volcanic rocks which underlie the northeastern corner of the map area. They consist of both pillowed and plagioclase-phyric basalts.

Minor felsic pyroclastic rocks are intercalated with the well-preserved metavolcanics southeast of the Schumann Lake area and with amphibolites near Highway 11, directly to the east of Island Lake. The presence of some disseminated sulphides in the pyroclastic rocks makes them an exploration target.

The felsic plutonic rocks in the southwestern corner of the area are a continuous with similar basement rocks described from Brigstocke and Kittson townships by Born and Burbidge (1987). They consist of a heterogeneous assemblage of both biotite- and hornblende-bearing tonalite, quartz diorite, mafic diorite, and diorite. Cross-cutting relationships indicate granodiorite and granite are the younger rock types. Also present are local migmatitic structures. Rare north- and northwest-trending, fine-grained Archean diabase dikes intrude the Archean felsic plutonic rocks. They generally range in width from 10 to 100 cm but may be up to 10 m wide. In the northeastern corner of the area near Chopin Lake, the felsic plutonic rocks are more homogeneous and consist only of a single lithology which is a reddish coarse-grained biotite-bearing granite also referred to as the Lorrain Granite (Lovell and de Grijs 1978).

PROTEROZOIC ROCKS

Early Proterozoic rocks of the Huronian Supergroup, namely the metasedimentary rocks of the Gowganda and overlying Lorrain formations underlie large parts of the map area. Subdivisions and descriptions of the individual units are similar to those reported for the adjacent area to the west by Born and Burbidge (1987). The Gowganda Formation consists of a lower unit, the Coleman Member, and an upper unit, the Firstbrook Member.

Rocks of the Coleman Member locally have a maximum thickness of 430 m. They occur as a blanket which unconformably drapes the Archean basement rocks. The member consists of a local basal conglomerate or basement regolith overlain by poorly sorted diamictites containing mud-, sand-, and gravel-sized constituents (Mustard 1985; Mustard and Donaldson 1987). Both massive and stratified matrix-supported diamictites occur and are believed to represent extensive debris flows. The stratification is probably indicative of reworking prior to the deposition of overlying debris flows. Trough cross-bedding is common in many of these rock types.

Clast-supported conglomerates and both pebbly and non-pebbly shaley mudstones with interlaminated siltstone and very fine sandstone are other common lithologies of the Coleman Member. Disappearance of the thin lenticular sandstone beds marks the upper limit of the Coleman Member. Metasedimentary rocks of the Coleman Member are characterized by rapid lateral lithofacies changes and the presence of "dropstones", all indicative of deposition in a glaciomarine environment at the edge of a continental ice shelf (Miall 1985).

The Firstbrook Member has an maximum thickness of about 260 m. It consists of a single, coarsening-upward sequence of fine-grained rocks (mud, silt, and minor very-fine sand Fl and Fr lithofacies (explained below); Miall 1978; Rust 1978a, 1978b).

These sediments overlie the Coleman Member and occur as a northwest-trending unit in the western part of Coleman and Gillies Limit townships. The sequence is divisible into a lower, middle, and upper unit following the criteria of Rainbird (1985) and Born and Burbidge (1987), although the uppermost unit is thin, poorly exposed, or absent in some parts of the map area. Interlaminated shaley mudstone and siltstone occur in the lower unit with silt making up <50 percent of the rock. Disseminated sulphides are locally present in this unit. In the middle unit, siltstone constitutes over 50 percent of the rock whereas in the upper unit the proportion of sandstone to siltstone plus shaley mudstone makes up more than 50 percent. Rare herringbone cross-laminations indicate a north-northeast/south-southwest bipolar paleocurrent direction for the Firstbrook Member.

The base of the Lorrain Formation is placed, following the criteria of Johns (1985), Rainbird (1985), and Born and Burbidge (1987) at the base of the lowermost medium or thickly bedded arkose unit.

Rocks of the lower Lorrain Formation locally have a maximum thickness of 650 m and underlie much of the southern and northwestern parts of the map area. The lowermost unit consists of a well-sorted, generally horizontally-laminated, very fine and fine-grained, thickly bedded arkose. Characteristic of this unit are local shaley rip-up clasts and some shallow scours. Commonly present are Sh (horizontally laminated sand), Sr (rippled sand) and Sl (low-angle trough cross-bedded sand) facies types (Miall 1978). Overlying this are thin local units of laminated shaley mudstones, siltstones, and very fine-grained sandstones. These represent Fl (laminated fine-grained mud) and Fr (rhythmically laminated fine-grained mud) lithofacies. Although these are not widespread, they are similar to parts of the Lorrain stratigraphic section found to the west in Brigstocke and Kittson townships (Born and Burbidge 1987). It is also similar in appearance to rocks of the upper and middle Firstbrook Member of the Gowganda Formation and suggests deposition in a similar deltaic environment.

Elsewhere, the uppermost exposed part of the coarsening-upwards cycles of the Lorrain Formation consists of a moderately to poorly sorted, medium-grained arkose with common planar and trough cross-beds. These represent St (trough cross-bedded sand) and Sp (planar cross-bedded sand) lithofacies (Miall 1978). Also present locally are some intercalated finer capping units (FCU) as described by Rice (1986, 1987, this volume) and Born (1986). These 510 cm arkose beds are mica-rich and consist of fine to very fine grained sand with common planar cross-beds.

The sediments of the Firstbrook Member (Gowganda Formation) and the Lorrain Formation represent a southward-prograding and coarsening-upwards marine wedge fed by a braided fluvial system. Upward facies transitions represent sedimentary environments ranging from prodelta through deltaslope and foreslope (Rainbird 1985; Rainbird and Donaldson 1988)) to tidal flat and channel; overlain by topset beds indicating braided stream sediments. Alternatively, the facies arrangements could indicate a delta to shallow marine transition. Marine depositional environments for the Lorrain Formation have been proposed by Hadley (1968) and by Rice (1986, 1987; this volume).

Early Proterozoic Nipissing diabase forms several east-trending sills (500 m thick maximum) which intrude all of the older lithologies. Contact metamorphism of the Proterozoic sediments resulted in chlorite spotting and epidotization in arkoses of the Lorrain Formation and shaley mudstones of the Gowganda Formation.

Coarse-grained quartz diabase and hypersthene gabbro are the main lithologies in the lower parts of the main diabase sill in the area. Along the lower contact of one of the sills for example, the diabase is fine grained, epidotized, and exhibits characteristic polygonal, columnar jointing. Coarse-grained varied textured gabbro is the main lithology of the upper portions of the sills and granophyre occurs sporadically along the upper contact of the sill where it is in contact with arkoses of the Lorrain Formation. Research by Conrod (1988) and Lightfoot *et al.* (1987) on the Nipissing Diabase sill at Portage Bay has provided a more detailed petrographic and geochemical interpretation for the petrogenesis of these sills.

The youngest Precambrian rocks in the area are represented by dikes of two lithologies.

Northwest-trending dikes of the Sudbury Swarm make up the first type, and have characteristic 1 to 2 cm plagioclase phenocrysts in an olivine-rich groundmass and are generally from 3 to 30 m wide. In the study area these dikes are only locally traceable.

The second type of dike found in the area is composed of lamprophyre. They consist of a coarse-grained biotite and muscovite matrix containing 5 to 30 percent rounded accidental clasts of Archean rocks. The vertical dikes are 10 to 30 m wide and generally trend in a northerly direction. Although not common in the Bay Lake area, they are similar to dikes in adjacent Brigstocke Township (Born and Burbidge 1987). The age of the dikes is uncertain and probably Middle Proterozoic or younger. They could be related to tectonic events associated with the Timiskaming Rift System (Lovell and Caine 1970).

STRUCTURAL AND METAMORPHIC GEOLOGY

Archean plutonic and metavolcanic rocks are generally weakly foliated with a near vertical east- to southeast-trending fabric. Brittle deformation and brecciation with some associated chloritization and quartz veining occurs locally along at least one south-southeast-trending shear which transects the Archean basement.

The Latchford Fault is probably part of the Timiskaming Rift Valley (Lovell and Caine 1970). It is a prominent northwest-trending fault which cuts across the central part of the map area. The Montreal River Fault is one of several additional northwest-trending faults and/or lineaments which are prominent throughout the map area. Displacement along these faults appears to be minor, and the local Huronian stratigraphic sequence is essentially intact with no apparent major horizontal or vertical displacements.

Sedimentary rocks of the Gowganda and Lorrain formations are undeformed in most places. They have undergone some folding (gentle flexure) during the Penokean Orogeny along several gently plunging (10°), subhorizontal, west- and east-trending fold axes. Only a few synclinal and anticlinal folds were observed. Some of the changes in the strike and dip of the strata may reflect faulting and subsequent tilting.

Locally extensive, post-depositional breccias occur mainly within rocks of the Gowganda Formation. The majority of the breccias are confined to vertical to sub-horizontal zones composed of angular 3 mm to 4 cm sized sedimentary clasts and 3 m blocks which show little or no internal deformation. Numerous local compressional kink bands occur in the adjacent host rocks of the breccias and are usually oriented in an easterly direction, commonly parallel to local fold axes. No extensional kink bands were observed. Similar breccias in Brigstocke and Kittson townships have been described by Born and Burbidge (1987). Field evidence in both areas suggested that the breccias were not caused by sedimentary slump failure but rather are related to the intrusion of Nipissing diabase. Steam or water escape processes, or both, were probable causes of the brecciation.

Another type of unusual breccia consists of subrounded and essential 2 to 4 cm clasts of arkose in a fine-grained sand matrix. They were found at one locality within rocks of the Lorrain Formation. These breccia bodies appear to be vertically oriented, and on horizontal ourcrop surfaces occur as irregularly-shaped isolated patches (10 to 30 cm diameter) within the sediments. Similar breccias occur to the west of the study area in Brigstocke and Kittson townships and have been described by Born and Burbidge (1987). Elsewhere in the Temagami (Burbidge, graduate student, University of Ottawa, 1987, personal communication) and Maple Mountain areas (Card *et al.* 1973) similar breccias also contain Nipissing diabase fragments. These breccias may represent gas escape features and/or may be related to lamprophyre dikes that commonly occur parallel to north- and northeast-trending structural lineaments. These types of breccias are referred to as Lake Temagami-type breccias (Born and Burbidge 1987).

The grade of regional metamorphism in the area varies from sub-greenschist facies in Middle Proterozoic age or younger olivine diabase and lamprophyre dikes, to lower greenschist facies in the Huronian sedimentary rocks, to amphibolite facies in the Archean metavolcanic and migmatitic/metaplutonic rocks.

ECONOMIC GEOLOGY AND RECOMMENDATIONS FOR FUTURE EXPLORATION

Copper, cobalt, silver, and gold mineralization is related to Nipissing diabase dikes and sills.

Located on the northeastern shore of Kitt Lake, the Shakt-Davis Mine has been developed at a deposit which consists of several major calcite veins hosted in a fractured and faulted zone within Nipissing diabase. The diabase intrudes arkoses of the Lorrain Formation and laminated shaley mudstones of the Firstbrook Member of the Gowganda Formation.

This fracture zone strikes 60°, parallel to a 120 m thick, vertical diabase dike. The Main Vein ranges in width from 1 to 7 m whereas the parallel Chimney Vein is from 1 to 3 m wide. Both are vertically oriented and contain smaltite, cobaltite, gersdorffite, erythrite (cobalt bloom), annabergite (nickel bloom), pyrite, chalcopyrite, and niccolite. Assays and analyses indicated 1.5 percent cobalt and minor silver over a width of 1.37 m, with select grab samples indicating up to 4 percent cobalt, and others with up to 2.72 ounces gold per ton. A further test of hand-picked ore indicated values of 0.87 ounce gold per ton, 0.25 ounce silver per ton, 7.92 percent cobalt, and 7.72 percent nickel; another smaltite ore sample returned 97 ounces silver per ton, 0.336 percent cobalt, and 0.18 percent nickel (Assessment Files, Resident Geologist Office, Cobalt). Grab samples collected by the author from the mine dump in 1987 yielded assay values of 0.10 ounce gold per ton and <0.10 ounce silver per ton, and analysis values of 2480 ppm cobalt, 580 ppm copper, and 7520 ppm nickel. Samples collected in 1988 indicated values of 5300 ppm cobalt, 53 ppm copper, and 7520 ppm nickel (Geoscience Laboratories, Ontario Geological Survey, Toronto).

The nearby Edison Mine is located 1.2 km to the east of the study area, at a deposit which hosts several mineralized calcite veins. Grab samples yielded values of 940 ppb gold, 17 ppm silver, 3.09 percent copper, and 3556 ppm cobalt (Geoscience Laboratories, Ontario Geological Survey, Toronto). This location is some 1.5 km to the south of the Cobalt-Kittson Mine in adjacent Kittson Township (Born and Burbidge 1987). Thus, the same narrow (70 m wide) Nipissing diabase dike hosts all three deposits.

Another area of extensive previous mineral exploration is the Portage Bay area. The best assay and analysis results were 7.95 percent copper and 1.96 ounces gold per ton from a drill intersection dating from 1952. Grab samples taken from several old pits yielded values of 480 ppb gold, 7 ppm silver, 1.48 copper, 6550 ppm cobalt, and 1740 ppm nickel (Geoscience Laboratories, Ontario Geological Survey, Toronto).

The Chopin Lake area is an area of extensive exploration located to the southeast of Schumann Lake. Here, Nipissing Diabase cuts basement Archean mafic volcanic rocks. Past exploration indicates the presence of some native silver and minor disseminated sulphides in several surface pits and in numerous drillhole intersections. Assays indicate maximum values which range from 2.4 ounces silver per ton over 18 cm to 90 ounces silver per ton over 5 cm. Samples taken from surface showings in the area by the authors during the 1988 fields season, however, yielded negligible results. Borden Lake, located further to the south of Schumann Lake, was also an area of concentrated exploration. The best results indicated cobaltite in some surface pits with 10 to 6 percent cobalt and some minor drilling indicated chalcopyrite, pyrite, galena, hematite, and pyrrhotite mineralization.

Scattered minor sulphide-bearing veins are also hosted in the Nipissing diabase at several localities along the upper contact of the sill in the vicinity of

Johnson Lake. Previous minor drilling and trenching indicated chalcopyrite, pyrite, galena, hematite, annabergite, and malachite mineralization with maximum silver values of 0.11 ounce silver per ton. Grab samples taken during 1988 indicated 1.41 copper with negligible gold and silver values. Another nearby sample from a road cut had values of 750 ppb gold with 6950 ppm copper. The deposit located on the Last Chance Mining property is hosted in the upper part of the sill along the railway north of Latchford. Sampling of the sulphide-bearing calcite vein material resulted in values of 780 ppm copper, 3800 ppm cobalt, and 600 ppm nickel (Geoscience Laboratories, Ontario Geological Survey, Toronto).

At several locations, mineralization consisting of disseminated pyrite and minor chalcopyrite occurs either within Archean plutonic/migmatitic and mafic metavolcanic rocks, or within quartz veins hosted by these lithologies. Previous diamond drilling and trenching west of Johnson Lake in Archean mafic volcanics outlined some minor chalcopyrite, pyrite, galena, hematite, annabergite, and malachite mineralization with maximum values of 2.4 ounces silver per ton and .02 percent copper over 24 cm. Grab samples taken in 1988 from a south-southeast-trending, pyrite-bearing shear zone gave assay values of 0.04 ounce gold per ton and <0.10 ounce silver per ton (Geoscience Laboratories, Ontario Geological Survey, Toronto).

The Rib Lake–Whitney Lake area straddles and extends south of the map sheet. Previous work outlined minor drilling and trenching, and indicated disseminated to massive pyrite, pentlandite, chalcopyrite, galena, and pyrrhotite mineralization. Maximum assay and analysis values included 0.01 to 5.3 ounces silver per ton, 0.004 to 0.01 ounce gold per ton, 0.03 to 0.38 percent copper (over an unknown width); and 0.2 to 1.3 ounces gold per ton over 1.7 m, and 0.05 to 1 percent nickel over 1.5 m.

Although many of these showings are minor, further prospecting could result in the discovery of more significant silver, gold, and/or base metal occurrences. The geological environment of the Bay Lake area is analogous to the Cobalt Camp (Legun 1986; Andrews *et al.* 1986) and thus further prospecting and exploration for Cobalt-type mineralization is recommended in this area.

The three potential areas for finding cobalt, copper ± silver, and gold-bearing veins are along the upper and lower contacts of the main east-west-trending diabase sill or along several north- and northeast-trending narrow (70 to 140 m wide) dikes in Kittson and Coleman townships. The presence of mineralized veins is structurally controlled. The veins occur in parallel fracture zones near margins of the diabase body. As a general rule, values of cobalt, silver, copper, and gold are usually higher in calcite rather than quartz veins. Gold values of more than 1 ounce gold per ton are associated with several cobalt-copper showings hosted in the Nipissing diabase. These are the Portage Bay occurrence in Coleman Township; the Shakt-Davis Mine in Kittson and Coleman townships; the Sugarloaf Island occurrence in Brigstocke Township (Born and Burbidge 1987); and the Temagami-Lorrain occurrence in nearby Cassels Township (Born 1986). The highest silver values are reported from drill data and indicate values of 90 ounces silver per ton over a width of 5 cm. These holes were drilled directly to the west of Chopin Lake in the northeastern corner of the map area. Several high gold values were also reported for sheared and sulphide-bearing Archean mafic volcanics in the Rib Lake and Whitney Lake areas. These values are 1.3 ounce gold per ton over 1.7 m (Assessment files, Resident Geologist Office, Cobalt).

All these occurrences are good indications of base and precious metal mineralization and make the study area and neighbouring areas promising exploration targets.

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41. Project Number 86-44. Regional Geology and Sedimentology of the Lorrain Formation, Cobalt Plain: Southeastern and Southern Outliers

Randy J. Rice

Geologist, Precambrian Geology Section, Ontario Geological Survey, Toronto.

INTRODUCTION

Prompted by anomalous Au values (up to 1.2 parts per million (ppm)) recovered from hematitic arenite and quartz pebble conglomerate lithofacies in the northwestern part of the Cobalt Plain (Colvine 1981, 1983), a regional sedimentologic study of the Lorrain Formation was initiated by the Ontario Geological Survey in 1986. The first (1986) and second (1987) field seasons were spent in the northern and central parts of the Cobalt Plain, respectively (Rice 1986, 1987). The third and final season, reported on herein, examined large outliers of the formation to the southeast and south of the main area of the Cobalt Plain. A final report, with maps, on the regional sedimentology and paleoplacer gold potential of the Lorrain Formation is due for completion in 1989.

The basal Huronian unit in both outliers is the Gowganda Formation. The Lorrain Formation constitutes the uppermost unit as stratigraphically higher Huronian formations (Gordon Lake, Bar River) are absent. The three-fold, largely compositional, stratigraphic subdivision first described for the Lorrain Formation by Collins (1917) continued to be used by the author during the 1988 field season. Collins (1917) distinguished the basal Lorrain as being feldspar rich, the middle Lorrain as being intermediate in feldspar content, and the upper Lorrain as feldspar impoverished.

The objective of this project is to establish the paleo-placer gold potential of the Lorrain Formation in the Cobalt Plain. As stated in Rice (1987), the determination of the depositional environment(s) present in the Lorrain Formation is crucial

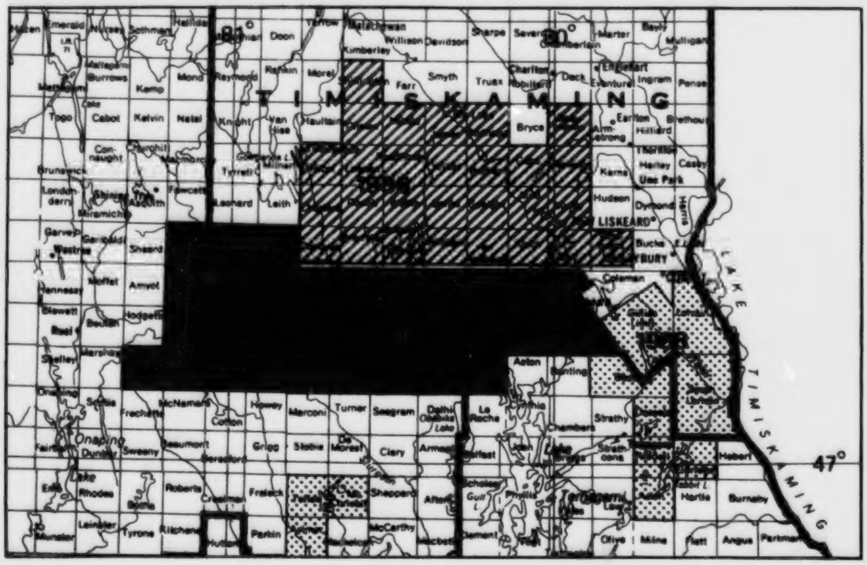


Figure 41.1. *Location map showing regions of Lorrain Formation outcrop examined during 1986, 1987, and 1988 field seasons. Scale: 1:1 584 000.*

CANADA ONTARIO

This project A.4.8 is part of the five year Canada-Ontario 1985 Mineral Development Agreement (COMDA), a subsidiary agreement to the Economic and Regional Development Agreement (ERDA) signed by the governments of Canada and Ontario.

to this evaluation. If the Formation is predominantly or entirely fluvial, then heavy mineral accumulations and conglomerates should be the best exploration targets. Alternatively, if the Formation represents a siliciclastic shelf environment, it would be unusual for an economic concentration of a heavy mineral to develop given the dispersive effect of the interacting current regimes that characterize an open shelf setting. Recently, however, placer accumulations have been reported from more restricted marine environments and attributed to intense sediment reworking in part due to storms (Hein and Syvitski 1988; Emory–Moore *et al.* 1988).

This report summarizes 1988 field work and presents 1987 analytical data (Au values) which could not be incorporated into Rice (1987). Ten sections were measured during the 1988 field season. In every instance, they were near vertical exposures which were only workable through the safe application of aid climbing techniques.

SUMMARY OF OBSERVATIONS

The Lorrain Formation was examined in two regions during the 1988 field season. A southeastern area, roughly bounded between Lady Evelyn Lake on the west and Lake Timiskaming on the east, incorporated several outliers of the Formation. A single, large, outlier of the Formation lying immediately north and northeast of Wanapitei Lake constitutes the second area investigated (Figure 41.1).

SOUTHEASTERN REGION

Lorrain Formation exposures in Kittson, Gillies Limit, Best, Cassels, Riddell, Askin, Eldridge, South Lorrain, and Lorrain townships were examined in this region. The work in Lorrain Township included reconnaissance (Ontario and Quebec shores) and section measuring along the Lake Timiskaming shoreline. One section was measured inland in Quebec, near Ville Marie. Exposures of both the basal and middle member of the Formation were examined in the southeastern region.

Basal Member

Lithofacies Description

Basal Conglomerate A basal Lorrain conglomerate unit has been previously described from Lorrain Township by Lovell and de Grijs (1976). During the past field season, this conglomerate was found at the granitic basement (Lorrain Granite, Thomson 1960) – Lorrain contact at three locations in Lorrain Township:

1. on a northwest–southeast–trending ridge located ca. 2 km south of Paradis Bay, Lake Timiskaming
2. approximately 1 km north of Latour Lake
3. on the northeastern shore of Pine Lake

This unit is lithologically similar at all three locations. It is a pink–green–grey–weathering, closed–work conglomerate that displays predominantly clast, and only local, matrix support. The percentage of matrix is variable but averages ca. 15 to 20 percent. Matrix in the conglomerate is a pale green weathering, commonly poorly sorted, fine– to very coarse grained feldspathic arenite. Clasts are almost in all places subround to well rounded and range in size from pebble to boulder. Clast shape is predominantly subequant with a significant number of prolate clasts. Four lithic clast types are recognized at the Paradis Bay locality; in descending order of abundance they are:

1. Pink–weathering granitic clasts ranging from pebble to boulder size; these are round to well rounded, commonly have diffuse boundaries with the adjacent matrix, occasionally display weathering rinds, and are much more abundant than all other clast types combined.
2. Pale tan to greenish weathering, fine– to medium–grained feldspathic arenite clasts; these are commonly in the pebble to cobble size range and are usually subround to round.
3. Maroon–weathering, subangular to well–rounded siltstone clasts commonly in the pebble size range (siltstone of the Firstbrook Member of the Gowganda Formation?).
4. Black–weathering (locally greenish), subround to round ultramafic volcanic clasts commonly in the pebble size range.

The exposures north of Latour Lake and on Pine Lake are not as clean as the Paradis Bay locality. Although it is not clear that at these northern localities the variety of clast types is present, it is clear that granitic lithics also predominate at these locations.

Very little organization is displayed by the conglomerate. Clast grading and imbrication are absent. However, occasional lenses (several tens of centimetres in length and ca. 5 to 20 cm thick) and thicker intervals (several tens of centimetres thick) of arenaceous matrix were observed, that in a few places display heavy mineral laminae and rippling.

The amount of matrix decreases toward the basement, as observed at Paradis Bay. The stratigraphically lowest exposures consist of large boulder size clasts of pink granitic basement displaying very diffuse margins with only thin stringers of intervening matrix. No organization is displayed at this stratigraphic level.

At the Paradis Bay locality, the contact between the basal conglomerate and the overlying Lorrain arenites is not exposed. However, a transitional arenite containing lenses and horizons of pebble size granitic lithics is present along a power line running between exposures of the basal conglomerate and overlying arenite. It is therefore inferred that the contact is transitional and conformable. Lovell and de Grijs (1976, p.6) described the contact as conformable and either transitional or sharp at other localities. The basal Lorrain conglomerate unit appears to be widespread in Lorrain Township.

Arenite The arenite portion of the basal member of the Lorrain Formation is commonly encountered throughout the southeastern region of the Cobalt Plain, and is consistent in its lithological makeup. It is composed of a predominantly pink– to grey–weathering, locally pale greenish weathering, grey or occasionally green–grey, principally fine– to medium–grained, locally very fine or coarse–grained, locally poorly sorted or moderate to well sorted, variably feldspathic arenite. While sedimentary structures are commonly encountered, significant areas of many exposures are non–stratified. Lamination and ripple cross–lamination, commonly accentuated by heavy minerals, are the most common sedimentary structures. Less common sedimentary features are: granule to pebble lag accumulations as pockets, lenses, and horizons that are commonly only several centimetres or less thick; isolated granules and pebble size clasts of quartz and feldspar; variably well–defined normally graded units that are 5 to 20 cm thick; trough and planar tabular cross–bedding; rare grey siltstone rip–up clast horizons of several centimetres maximum thickness; rare convoluted stratification. No representative sequence of primary sedimentary structures could be established for arenite units defined in the basal Lorrain Formation.

The lithofacies sequence reported previously by Rice (1986, 1987) for the Lorrain Formation in the northern and central part of the Cobalt Plain is also present in the basal Lorrain in the southeastern region. Arenite units in this area are commonly ten centimetres to several metres thick and characteristically separated by either a usually greenish weathering, slightly micaceous, finer grained arenite/coarse siltstone lens that is centimetres to several tens of centimetres thick and commonly several metres in length, or separated by an amalgamation surface representing the erosional removal of the finer grained lens during the emplacement of the overlying arenite body. These finer grained lenses have been previously referred to as finer grained capping units (fcu) by Rice (1986, 1987), since the character of their basal contact with the underlying coarser arenite is most commonly either gradational or sharp while that of their upper contact is usually erosional. The fcu are characteristically featureless but occasionally will display ripple cross–lamination or isolated quartz and feldspar granules. The fcu were not always present in the basal Lorrain arenite. They were absent along the eastern shore of Rib Lake and Rabbit Lake, at Crowrock Bay on Anima Nipissing Lake, and along the northeastern shore of Pine Lake. While their absence on Pine Lake may only be apparent due to the poor nature of the exposures, their absence at the other localities may be a function of the proximity to the contact with the Firstbrook Member of the Gowganda Formation. The section measured on Rabbit Lake and at Crowrock Bay on Anima Nipissing Lake were both in the Firstbrook–Lorrain transition zone and the Rib Lake exposures were proximal to this zone as well. It may be that Lorrain depositional conditions need to be fully established before this lithofacies sequence develops. However, it appears that the rapidity of the development of such conditions was variable since fcu are present in the basal Lorrain arenite within several metres of the contact with the Firstbrook at the Kit Ravine locality in Kittson Township.

Middle Member

Lithofacies Description

Arenite The middle Lorrain arenite is common throughout the southeastern region of the Cobalt Plain. In general, it is less feldspathic and coarser grained than the basal arenite. The middle arenite is predominantly green–white to green–grey on both weathered and fresh surfaces. Weathered surfaces can also be grey–white or pinkish–white and fresh surfaces will locally display a grey or green colour. It is dominantly medium to coarse grained, but locally contains finer or coarser sand sized detritus. Sorting is commonly poor, but moderate to well–sorted exposures are also present.

Sedimentary structures are more abundant in the middle arenite than they are in the basal arenite. Again, no characteristic assemblage was identified. The most common sedimentary features encountered are: isolated quartz and feldspar clasts; lenses or horizons of granule to lower pebble size quartz and feldspar lag occasionally containing slightly smaller jasper clasts or granitic lithics; variably well–defined normally graded units commonly 5 to 20 cm thick; ripple cross–lamination; and heavy mineral lamination. Less commonly encountered sedimentary structures or features include: planar tabular and trough cross–bedding; foreset grading; and siltstone clasts.

The lithofacies sequence described above for the basal arenite is also present in the middle arenite (Photo 41.1). The fcu in the middle arenite tend to be darker green in colour and to display more sedimentary features; these include: isolated quartz and feldspar granules; lenses of coarser grained sand sized detritus; heavy mineral lamination; ripple cross–lamination; asymmetrical waveforms along the top contact with the overlying coarser arenite; normally graded units several centimetres thick; and rare small–scale planar tabular cross–strata. The geometry and scale of the fcu in the middle arenite are similar to that reported for the basal arenite. Fcu are present at all exposures of the middle arenite examined during the 1988 field season. A measured section from the middle member arenite in Lorrain

Township, immediately adjacent to Lake Timiskaming, is presented as Figure 41.2.

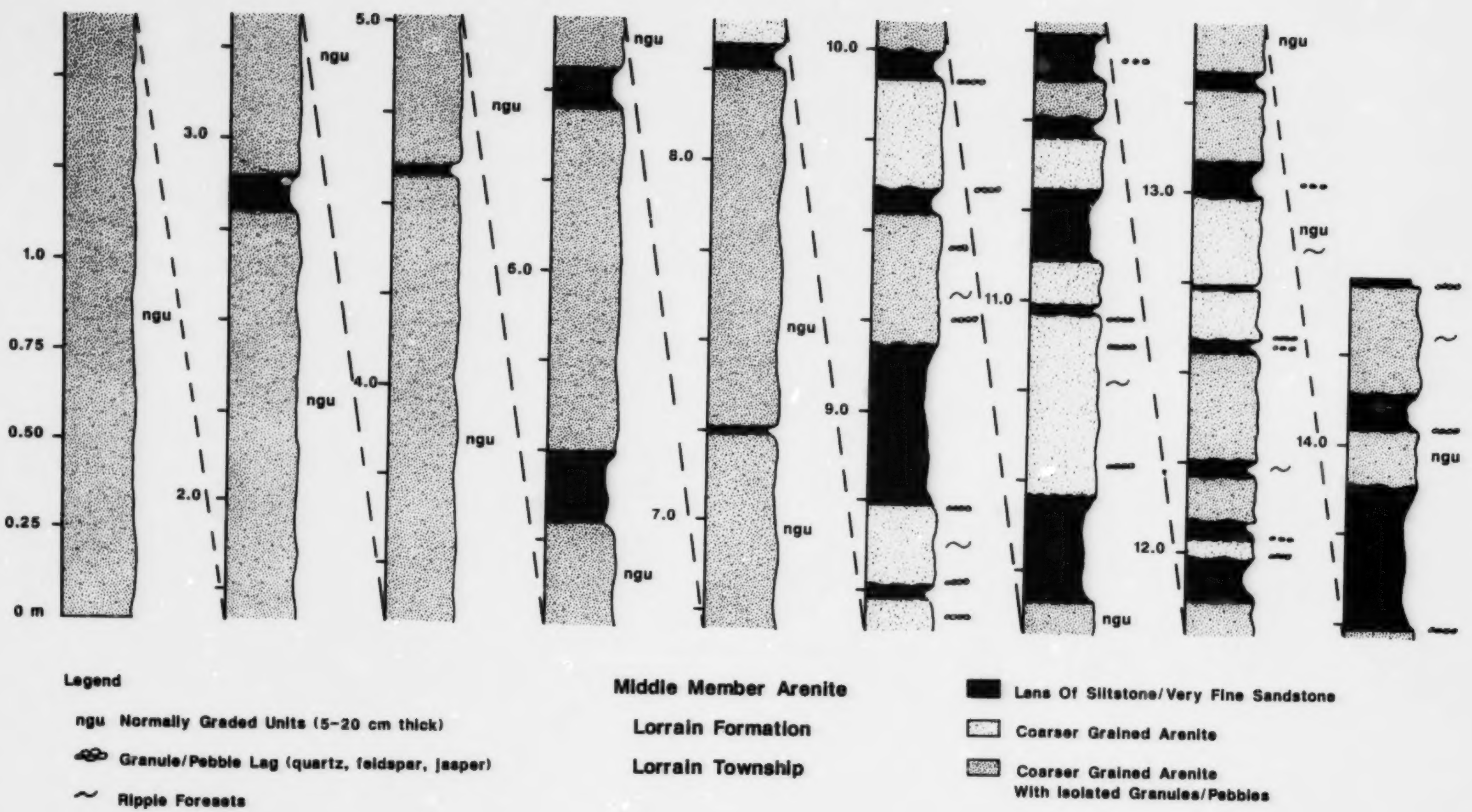
A newly observed feature of the middle arenite is occasional laminae consisting of yellow– to brown–weathering clay sized detritus (Photo 41.2). This sediment occurs as both lamination and on cross–stratification in the coarser arenite units as well as the fcu, and was encountered on the southern side of the first ridge south of Mission Point on Lake Timiskaming in Lorrain Township, on north, central, and south Lorrain Lake in South Lorrain Township, on the western side of Friday Lake in Best Township, and on the southern shore of eastern Blueberry Lake in Cassels Township.

Lithofacies Interpretation—Southeastern Region

Basal Member Conglomerate

Lovell and de Grijs (1976) tentatively suggested that the entire basal conglomerate unit in Lorrain Township represents a regolith. It is herein suggested that the basal conglomerate unit in Lorrain Township largely represents a proximal to upper intermediate alluvial fan setting developed in association with Early Proterozoic fault activity related to the Timiskaming and Cross Lake faults. Debris flow and stream flow processes were operative during its deposition, the former being overwhelmingly dominant. The scarcity of sorting, and very poor organization are complimentary in suggesting a debris flow mechanism. The occasional lens or horizon of poorly sorted arenite in the conglomerate is interpreted to represent stream flow reworking of debris flow surfaces. Proof of reworking lies in the occasional presence of exotic clasts of ultramafic volcanics, arenites, and siltstones in both the conglomerate and arenite units, as well as heavy mineral laminae and ripple lamination in the arenite. Matrix content decreases and exotic lithics and organization are lost as proximity to the granitic basement increases. In the lowest exposures, rounded to well–rounded cobble and boulder size granitic clasts display a diffuse interface with the small amount of matrix remaining (*see* Lovell and de Grijs 1976, Photo

Photo 41.1. *The lithofacies sequence displayed by the middle member arenite in Lorrain Township immediately adjacent to Lake Timiskaming. The lighter coloured intervals are coarser grained feldspathic arenite. They are separated by darker coloured (green) horizons (referred to as finer grained capping units (fcu) in text) (arrows) composed of slightly micaceous finer grained arenite to coarse siltstone. This is the same lithofacies sequence that was reported for the Lorrain Formation in the northern and central part of the Cobalt Plain in Rice (1986, 1987). John Burton, M.Sc. candidate, Lakehead University, is examining the near vertical exposure with climbing ropes.*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Granule/Pebble Lag (quartz, feldspar, jasper)
Ripple Foresets
Middle Member Arenite
Lorrain Formation
Lorrain Township
Lens Of Siltstone/Very Fine Sandstone
Coarser Grained Arenite
Coarser Grained Arenite With Isolated Granules/Pebbles

Figure 41.2. *Measured section in the middle member Lorrain arenite immediately adjacent to Lake Timiskaming in Lorrain Township. A part of this section is shown in Photo 41.1.*

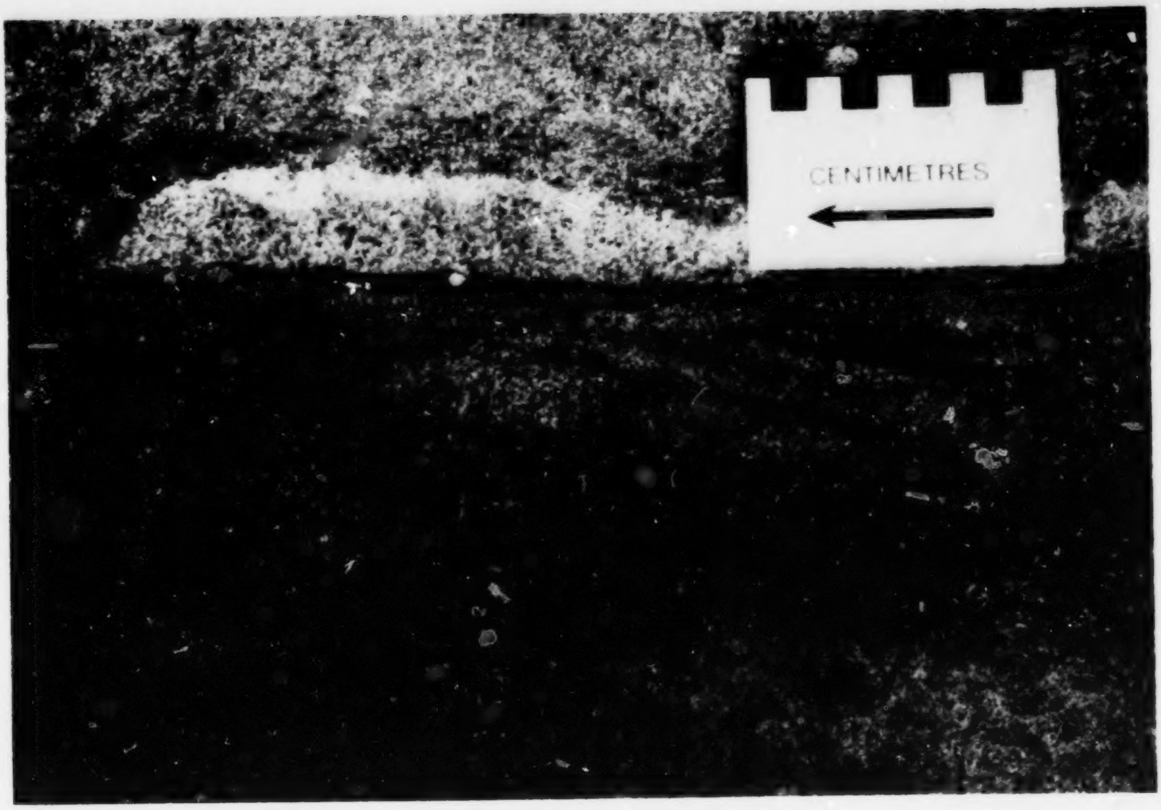

Photo 41.2. *Possible clay drapes (arrows) in the middle member arenite exposed on the western shore of central Lorrain Lake in South Lorrain Township. Positive identification requires petrographic examination (see text).*

1, p.7). This fabric is interpreted to represent a regolith developed between the granitic basement and the overlying alluvial fan debris flow deposits.

Basal and Middle Member Arenite

As the same lithofacies sequence is displayed by the arenite units in the basal and middle member of the formation in the southeastern region, a similar interpretation of the paleoenvironment may be offered for both. This sequence is precisely that which was observed in the Lorrain arenites in the northern and central part of the Cobalt Plain. As such, the siliciclastic shelf hypothesis suggested by Rice (1986, 1987) for the Lorrain Formation arenites is retained for the arenites observed during the 1988 field season. Briefly stated, this hypothesis suggests that coarser arenite units which are separated by fcu units represent above fair weather wave base deposition of sand size detritus, while fcu units represent post–storm partial preservation of finer grained detritus deposited on the shelf during an earlier period of lowered ambient energy.

The clay laminae reported above for the middle member arenites were not seen during the 1986 or 1987 field seasons. Prior to establishing their primary or secondary nature, the author is reluctant to use the term clay drapes for these laminae. If the clay is not diagenetic, then periods of cessation or near cessation of flow are indicated. However, as is characteristic for Lorrain arenites, the identification of this depositional process would not provide diagnostic evironmental evidence.

SOUTHERN OUTLIER

Middle Member

Lithofacies Description

Arenite Middle member arenite units in the Lorrain Formation were examined in McConnell, Telfer, and Aylmer townships via lakeshore investigations around the margins of Chiniguchi Lake. The middle member arenite in this area is similar to that described from the southeastern region. It is characteristically green–white to green–grey on both weathered and fresh surfaces with occasional additional pinkish hues. It is feldspathic, locally poorly sorted, and commonly coarse grained, ranging from medium to very coarse sand size. As was the case for the southeastern region, no characteristic sequence of sedimentary structures could be established for the arenite units. Sedimentary features are common, however, and include: millimetre to several centimetre thick horizons and lenses of quartz and feldspar granule lag; isolated granule to lower pebble size quartz, feldspar, and, rarely, jasper clasts; several centimetre to several tens of centimetre thick normally graded units; planar tabular and trough cross-stratification occasionally showing foreset grading; occasional heavy mineral laminae; relatively uncommon penecontemporaneous deformation features; and rare granitic or siltstone lithics in isolation or as part of lag units.

The previously described sequence of coarser arenite units separated by fcu is present in all the outcrop examined around Chiniguchi Lake. The fcu in this region are light to dark green in colour and can vary from several centimetres to several tens of centimetres (to 40 to 50 cm) in thickness. They are either featureless or display one or more of the following: basal quartz and feldspar granule lag horizons; isolated quartz and feldspar granules; heavy mineral laminae; ripple cross-lamination; occasional clay laminae on ripple foresets and as subhorizontal lamination; rare cross stratification approximately equalling the thickness of the fcu.

Lithofacies Interpretation

The sedimentary features and lithofacies sequence displayed by the middle member arenite in the

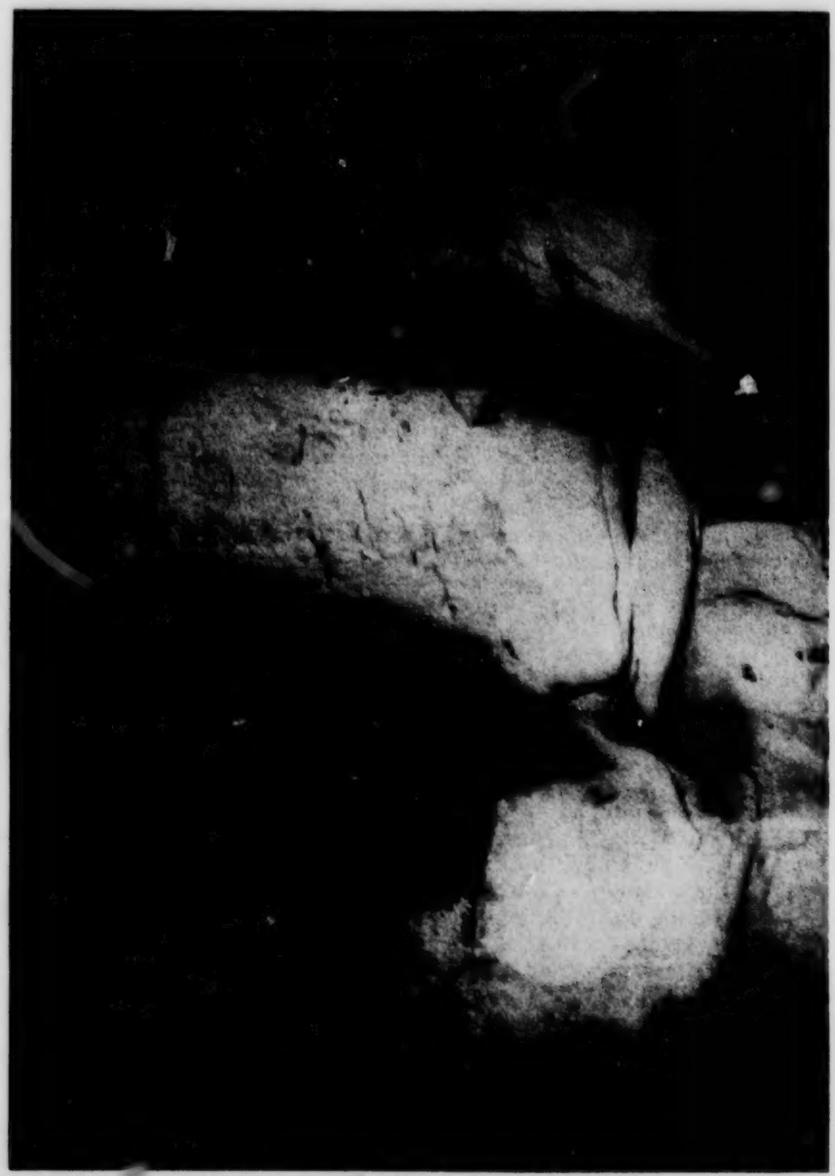

Photo 41.3. *The lithofacies sequence displayed by the middle member arenite on Chiniguchi Lake, McConnell Township. The recessive weathering units (arrows) represent finer grained capping units (fcu in text). This sequence is similar to that observed in Lorrain Formation arenites throughout the Cobalt Plain. The upper recessive unit is ca. 45 cm thick.*

Chiniguchi Lake region is similar to that found in all other regions of the Cobalt Plain (Photo 41.3). The siliciclastic shelf hypothesis (Rice 1986, 1987) is therefore extended to this region.

PALEOCURRENT DATA

Most of the field season was spent in the southeastern region of the Cobalt Plain. Only sparse paleocurrent measurements were recovered from the basal and middle member Lorrain arenites in this area. This is in part a reflection of the regional nature of the field work, but is also an indication of the relative scarcity of directional data in this area. The data indicate a range in transport direction between the southwest and southeast with the former dominating. This data is similar to that reported from the central and northern region of the Cobalt Plain (Rice 1986, 1987).

DISCUSSION

Basal Conglomerate Unit

The alluvial fan–regolith interpretation suggested for the basal member basal conglomerate in Lorrain Township complicates the environmental setting for the Lorrain Formation in the Cobalt Plain. This unit is important in developing a depositional hypothesis for the Lorrain Formation, since the contact between it and the overlying basal member arenite is conformable and either transitional or sharp (Lovell and de Grijs 1976; this study). Whether this unit assumes a regional or only local significance in the environmental scenario for the Lorrain Formation depends on its areal extent in the Cobalt Plain and, if areally extensive, the regional character of its contact with the overlying basal member arenite. Granitic basement and the Lorrain Formation are areally juxtaposed only on the southwestern and southeastern margins of the Cobalt Plain. While the basal conglomerate unit appears to be extensive in Lorrain Township (southeastern region), its presence or absence could not be established in the southwestern region during the 1988 field season. The contact zone was not exposed at localities checked in Fraleck and Valin townships, however, a thorough search of the southwestern region could not be conducted due to time constraints. Future work on the Lorrain Formation must put a priority on establishing the presence or absence of the basal conglomerate unit in this area of the Cobalt Plain. Nevertheless, at least for Lorrain Township, preference for a marine interpretation of the Lorrain Formation requires that alluvial fan facies are transitional into a marine shelf setting.

Gowganda (Firstbrook Member)—Lorrain Transition

The nature of the Gowganda–Lorrain and Lorrain–Gordon Lake contact is important in any attempt to interpret the depositional environment of the Lorrain Formation. These contacts warrant a separate study which could not be conducted simultaneously with the current project. The Lorrain–Gordon Lake contact was not observed during the past three field

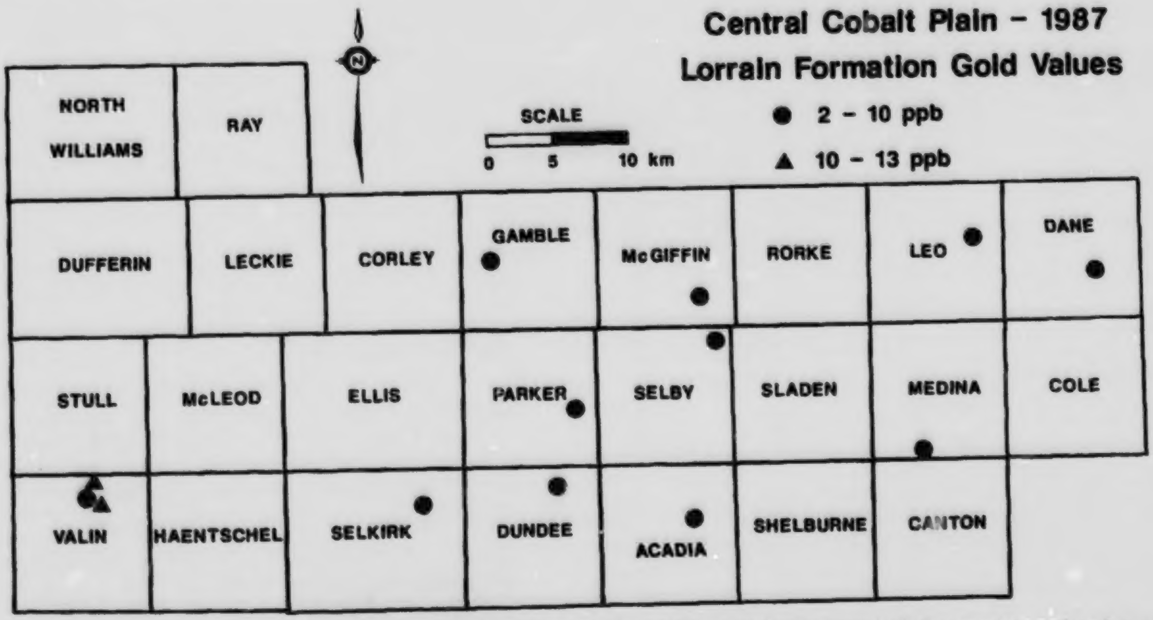

Figure 41.3. *Gold values recovered from Lorrain arenites and conglomerates (only several of the samples analyzed were conglomerates) sampled in the central Cobalt Plain during the 1987 field season. Only those samples are shown which had values equal to or above the detection limit (2 ppb). Analyses were performed by the Geoscience Laboratories, Ontario Geological Survey, Toronto.*

seasons in the Cobalt Plain. The Gowganda–Lorrain contact was observed in the southeastern outlier at three locations: Kit Ravine – Kittson Township; Crowrock Bay of Anima Nipissing Lake – Kittson Township; and Rabbit Lake – Eldridge Township. On Crowrock Bay and on Rabbit Lake, the contact is conformable and transitional. At Kit Ravine, the contact is transitional as well, with some erosion due to a flow event which occurred in early Lorrain time locally eroding down into the Firstbrook Member of the Gowganda Formation. The transitional nature of this contact is herein considered more supportive of a marine rather than a fluvial depositional setting for the Lorrain Formation in light of the current marine deltaic depositional model suggested for the Firstbrook Member of the Gowganda Formation (Junnila 1986; Rainbird and Donaldson 1988). Rainbird and Donaldson (1988) used the transitional contact to suggest that the overlying Lorrain Formation is the subaerial braidplain part of a deltaic wedge. However, it is here suggested that a lateral facies shift in association with subsidence resulted in a Lorrain shelf overlying a Firstbrook marine delta. Since the Firstbrook delta had to have prograded onto a shelf, it is just as reasonable to suggest the presence of laterally equivalent shelf facies as it is for Rainbird and Donaldson (1988) to suggest laterally equivalent subaerial deltaic facies. Born and Burbidge (1987) presented evidence of apparent interfingering of Firstbrook and Lorrain facies on Anima Nipissing Lake in Brigstocke Township.

LABORATORY RESULTS

The results of analyses for gold by the Geoscience Laboratories, Ontario Geological Survey, Toronto, on samples collected during the 1987 field season are presented in Figure 41.3. This figure indicates that values range only between 2 and 13 ppb. While most of the samples analyzed were arenites, several quartz granule–pebble conglomerate samples are also represented in this figure.

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42. Breccias of the Sudbury Structure, District of Sudbury

M.E. Avermann and V. Mueller–Mohr

Graduate Students, Institute of Planetology, University of Muenster, Federal Republic of Germany.

INTRODUCTION

The investigations carried out by M.E. Avermann and V. Mueller–Mohr form part of a co-operative scientific project between the Ontario Geological Survey and the University of Muenster, Federal Republic of Germany. This project, initiated in 1984, will hopefully lead to a better understanding of the origin of the breccias in the footwall of the Sudbury Igneous Complex and the breccias of the Onaping Formation, as well as the origin of the Sudbury Structure itself. The present studies are in partial fulfillment of the requirements for a Ph.D. degree at the University of Muenster.

The Sudbury Breccias were studied over a large area; mainly in the South Range of the Sudbury Structure and in a few locations to the northeast (Figure 42.1 and Figure 42.2). The Onaping Formation was studied in the southeastern part of Capreol Township and forms part of an area previously mapped by Muir (1981). Access to this area is provided by a gravel road that extends off Regional Road 86 to Skead.

MINERAL EXPLORATION

It is beyond the scope of this report to describe the mineral exploration carried out in the areas of investigation. The most productive nickel–copper sulphide deposits of the Sudbury District are located in the southern parts of the study area. In some places the Sudbury Breccia occurs in close spatial relationship to the sulphide–bearing Sublayer (e.g. Frood–Stobie Mine, McKim Township, Dressler 1984). For detailed information the reader is referred to Pye *et al.* (1984).

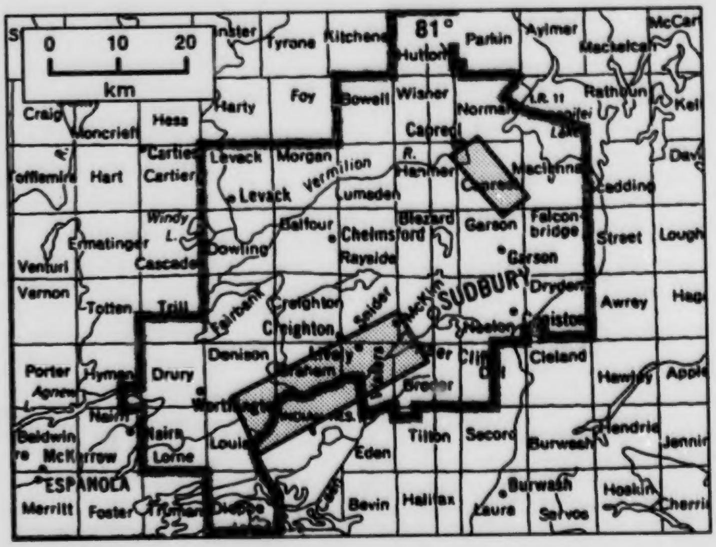
To the authors' knowledge no significant mineralization occurs within the breccias of the Onaping Formation in Capreol Township.

FIELD INVESTIGATIONS

STUDY OF THE SUDBURY BRECCIA

V. Mueller–Mohr

The Sudbury Breccias are interpreted to be pseudotachylite–like rocks occurring in the footwall of the Sudbury Igneous Complex (Dressler 1984). They have also been described as occurring as fragments in the Footwall Breccia, and as inclusions in the Sublayer (Dressler 1984). The spatial distribution of the Sudbury Breccia surrounding the Sudbury Igneous Complex illustrates a close genetic relationship between the breccias and the Sudbury Structure. The breccia has been studied on a regional basis by several workers (e.g. Dressler 1984; Mueller–Mohr 1988). During the 1988 field season, many samples


0
10
20
km
81°
Tyrone
Kitchener
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McCar
Hutton
Harty
Foy
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Wisner
Norman
Rathbun
Kel
Craig
Hess
Moncrief
Capreol
Lake
Cartier
Levack
Morgan
Vermilion
R.
Hanmer
Maclennan
Dav
Toffiemire
Hart
Cartier
Levack
Lumsden
Capreol
Cedding
Windy L.
Balfour
Chelmsford
Blezard
Garson
Falconbridge
Street
Lough
Ermatinger
Dowling
Rayside
Garson
Venturi
Cascade
SUDBURY
Dryden
Vernon
Totten
Trill
Fairbank
Creighton
Snider
McKim
Awrey
Hag
Creighton
Neelon
Coniston
Denison
Lively
Cleland
Porter
Hyman
Drury
Graham
Cliff
Hawley
Apple
Agnew
Broder
Nairn
Tilton
Secord
Hendrie
Baldwin
Nairn
Louis
Burwash
Jennin
McKerrow
Lorne
Eden
ESPANOLA
Burwash
Hoskin
Merritt
Foster
Bevin
Halifax
Laura
Servos
Cherri

Figure 42.1. *Location map of Sudbury area.*

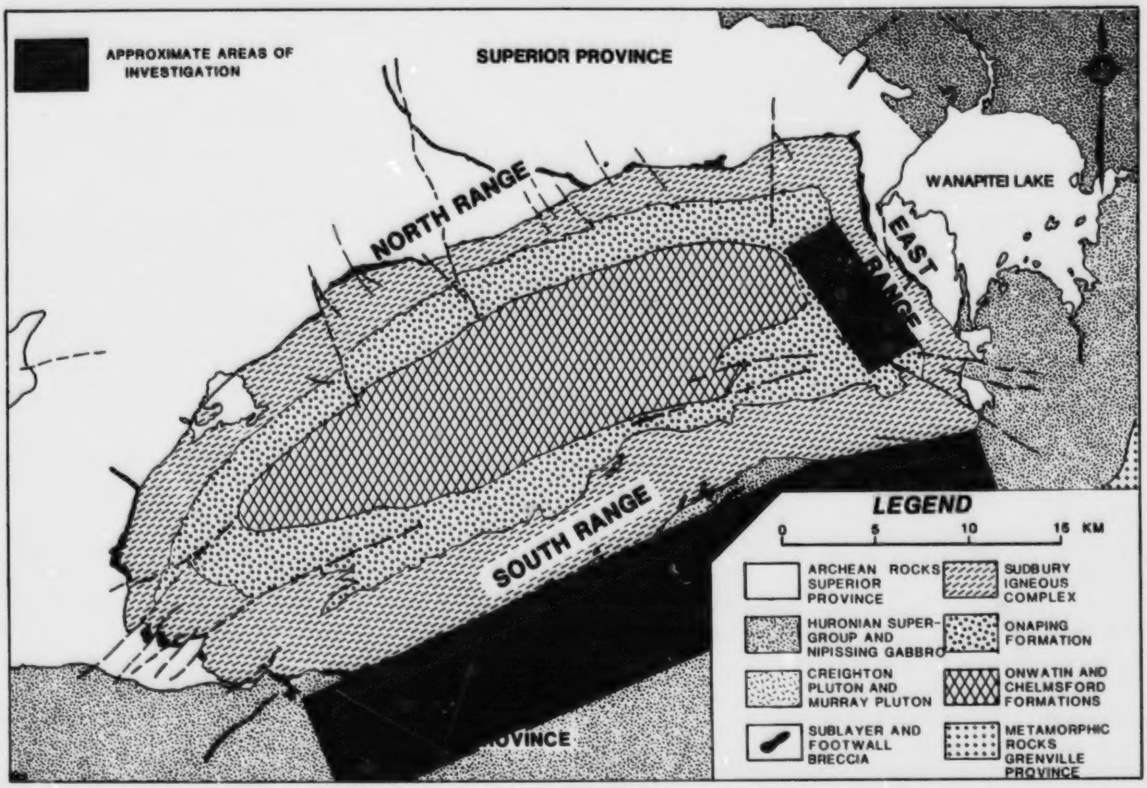
APPROXIMATE AREAS OF INVESTIGATION
SUPERIOR PROVINCE
NORTH RANGE
EAST RANGE
WANAPITEI LAKE
SOUTH RANGE
OVINCE
LEGEND
0
5
10
15 KM
ARCHEAN ROCKS SUPERIOR PROVINCE
SUDBURY IGNEOUS COMPLEX
HURONIAN SUPER-GROUP AND NIPISSING GABBRO
ONAPING FORMATION
CREIGHTON PLUTON AND MURRAY PLUTON
ONWATIN AND CHELMSFORD FORMATIONS
SUBLAYER AND FOOTWALL BRECCIA
METAMORPHIC ROCKS GRENVILLE PROVINCE

Figure 42.2. *The Sudbury Structure and the location of field areas in South Range and East Range.*

were taken for petrographic and geochemical investigations. These samples of Sudbury Breccia will be compared to samples of the breccia taken in parts of Levack Township adjacent to the contact with the Igneous Complex and along Highway 144 up to 55 km away from the Complex (Avermann and Mueller–Mohr 1986). The Sudbury Breccia will be compared with breccias from known meteorite impact craters and other terrestrial structures in order to gain a better understanding of the origin of both the Sudbury Breccia and the Sudbury Structure.

The Sudbury Breccias occur as dikes or irregular shaped bodies that range in size from a few millimetres wide and tens of millimetres long to zones tens of metres in size. The largest zone of breccia described by Dressler (1982) is about 0.35 km wide and approximately 11 km long. Fragments in the breccia are subangular to rounded, and in a few places distinctly deformed and elongated. Fragments of sedimentary rocks are commonly deformed. Contacts of the matrix with the fragments and the host rock are generally sharp. In some outcrops, however, flow lines surrounding the fragments give the appearance of a transition between fragment and matrix. Fragments are commonly derived from the host rock in the immediate area. These observations are not new and have been made by previous workers (e.g. Dressler 1984).

The matrix of the breccia generally consists of very fine–grained rock flour. In a few places, an igneous–looking or recrystallized matrix points to the involvement of a melt phase during the generation of the breccia. In some breccia dikes evidence for more than one phase of brecciation is found. For example, fragments of breccia can be found within a breccia body; where the matrix of the breccia fragment exhibits a sharp contact with the matrix of the main breccia body. Compared to the North Range, flow line and schlieren–type textures in Sudbury Breccia samples are more common within the South Range. A distinct schistosity in the matrix has resulted from the Penokean Orogeny.

STUDY OF THE ONAPING FORMATION IN THE EAST RANGE OF THE SUDBURY STRUCTURE

M.E. Avermann

The rocks of the Onaping Formation were referred to as volcanic breccias, glowing avalanche deposits, Peléan domes, and impact fall back breccias (Burrows and Rickaby 1930; Williams 1957; Peredery 1972).

The author started detailed mapping of the Onaping Formation in the southern part of the East Range of the Sudbury Structure. The investigations confirmed the subdivision of the formation into the Basal Member; the Melt Bodies; the Gray Member;

and the Black Member (Peredery 1972; Muir and Peredery 1984).

The contacts of the Basal Member with the granophyre of the Upper Zone of the Sudbury Igneous Complex and with the plagioclase-rich granophyre are intrusive, but in places gradational. Due to the contact metamorphic overprinting by the Sudbury Igneous Complex, the matrix of the Basal Member has a pinkish-gray colour, and some leucocratic fragments (such as granitic and arkosic fragments) readily show contact metamorphic features.

Attempts were made to characterize the fragment population; the abundance and size of fragments in each mappable unit of the Onaping Formation; and to compare the rock fragments with the footwall rocks of the Sudbury Structure.

Shock metamorphic features were recognized within both the Melt Bodies and the Gray and Black members. Within the Gray Member, contacts were noted and were traceable over short distances (Muir and Peredery 1984). The contact between the Black Member and the Gray Member is not easy to define everywhere. The chlorite shard horizon (Muir and Peredery 1984) is poorly developed or absent within the study area. Both fragment size and the abundance of country rock fragments decrease upwards in the Black Member. The carbon content, however, increases and is responsible for the dark colour of this breccia unit (Muir and Peredery 1984). The contact between the Onaping Formation and the overlying mudstones of the Onwatin Formation is gradational, as has been described at other places within the Sudbury Structure (Pye *et al.* 1984). During the field work, a large number of specimens were taken for petrographic and geochemical investigation. The study of shock metamorphic features, and the geochemistry of breccia matrices and fluidal glasses will be of interest.

The authors gratefully acknowledge the assistance obtained during the field investigations from the management and the geological staff of Falconbridge Limited and Inco Limited.

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43. Project Number 88–05. Regional Mapping and Stratigraphic Studies, Grenville Province with some Notes on Mineralization Environments

R.M. Easton

Geologist, Precambrian Geology Section, Ontario Geological Survey, Toronto.

INTRODUCTION

A geological synthesis of the Grenville Province in Ontario is being undertaken as part of the Geology of Ontario project. This synthesis involves both the preparation of a series of 1:50 000 and 1:250 000 scale geological maps of the Grenville Province in Ontario, as well as a synthesis of the geology of the Grenville Province, particularly with respect to controls on mineralization. Fieldwork in 1988 involved mapping related to the preparation of several 1:50 000 and 1:250 000 scale compilation maps, in addition to some regional studies that examined several poorly known areas and structural features of the Grenville Province (Figure 43.1).

COMPILATION MAPPING

About a week was spent mapping in the McKellar area, in order to correlate lithologies and major structures within the northern part of the Parry Sound Domain. The McKellar area was originally mapped by Lacy (1960), and this field work will assist in the preparation of a 1:50 000 scale compilation map of the northern half of the Parry Sound Domain, incorporating the mapping of Bright (1987) and McRoberts and Tremblay (1988) of the Ontario Geological Survey and Davidson and co–workers at the Geological Survey of Canada (Davidson *et al.* 1982).

One week was spent mapping in the Tomiko–North Bay area in conjunction with the preparation of 1:250 000 scale compilation maps of the area. This area has been well–mapped at 1:63 360 scale by Lumbers (1971a, 1971b, 1971c, 1973, 1975). No significant changes have been made to Lumbers' maps; however, the pattern of lithological units, structural trends, and location of major deformation zones in the area is analogous to the patterns present in the Parry Sound area, and a preliminary attempt was made to subdivide the Tomiko–North Bay area into a number of lithotectonic domains (Figure 43.2). Additional work is needed to define these domains on a finer scale, and to study the nature of their boundaries more fully, particularly as some of the boundaries have been re–activated during faulting associated with the Nippissing–Ottawa Valley Rift, whereas others are narrower than terrane boundaries described in the Parry Sound area (Davidson *et al.* 1982).

In the River Valley and Tomiko areas, Lumbers (1971b, 1971c, 1973, 1978) defined the Red Cedar Lake Formation. This unit occurs as a band, up to 15 km wide, that lies immediately south of, and parallel to, the Grenville Front from River Valley to the Ottawa River (Figure 43.2). Lumbers (1978) interpreted this unit as an Early Proterozoic, conglomeratic greywacke sequence, possibly representing a turbidite fan system that developed on Archean basement at the edge of an Early Proterozoic continental margin. The unit was subsequently metamorphosed and deformed during the Grenville Orogeny.

The Red Cedar Lake Formation is a distinctive unit, best described as a granular gneiss. In places it appears to represent a series of deformed augen gneisses probably derived from deformed metaplutonic rocks. Elsewhere, it can be termed a porphyroclastic gneiss (Davidson *et al.* 1982), derived from an undetermined protolith. Although Lumbers (1978) may indeed be correct in his interpretation of this unit, due to the extreme deformation and metamorphism, the protolith of these granular gneisses is for the most part problematic. However, the unit is distinctive, and mappable, and it is suggested that the term Red Cedar Lake Formation be retained, but redefined as the Red Cedar Lake Gneiss, with reference sections on Red Cedar Lake, on Highway 805 and the CPR railway 0.5 km south of River Valley, and on Highway 11 between Marten River and Opechee Creek.

Field Work was also conducted for compilation of 1:50 000 scale maps of NTS areas 31C/10 (Tichbourne), 31C/11 (Kaladar), 31C/14 (Mazinaw Lake), 31E/1 (Wilberforce), 31E/2 (Haliburton), and 31F/3 (Denbigh).

FRONTENAC–SHARBOT LAKE TERRANE BOUNDARY

About ten days were spent mapping the Frontenac–Sharbot Lake Terrane Boundary in the area between Tichborne and Carleton Place (Figure 43.3) in order to better delineate this boundary, and to determine if units could be correlated across it. Although this boundary separates granulite–facies

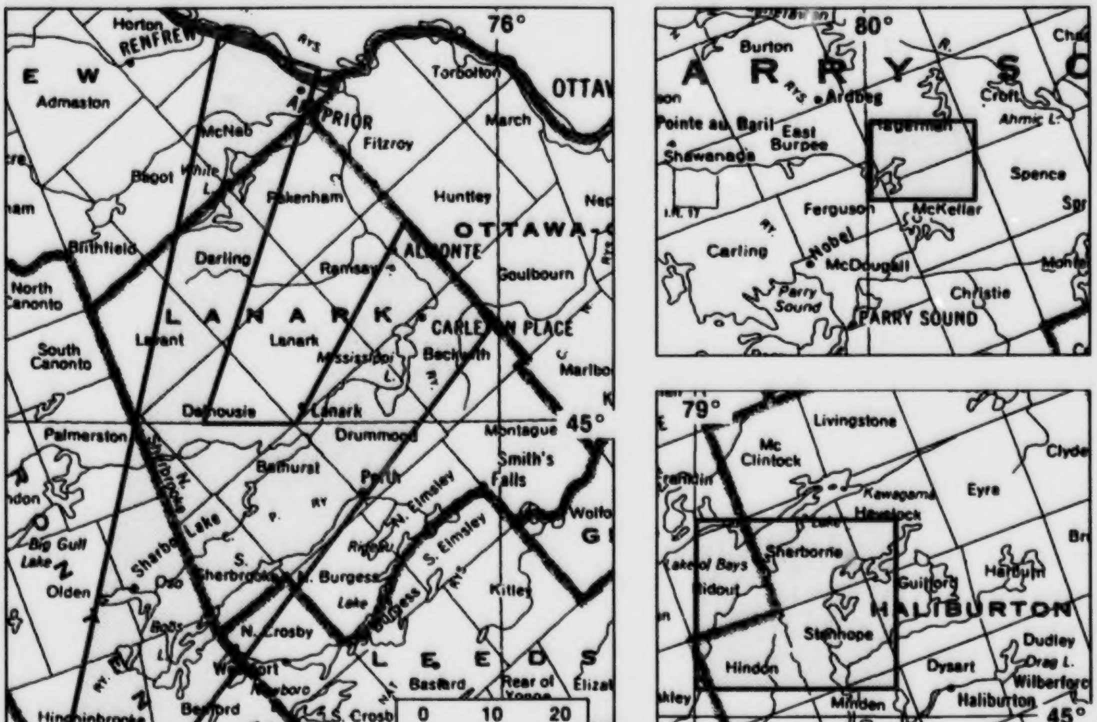
76°
Horton
RENFREW
ARNPRIOR
Torbolton
OTTAWA
Admaston
McNab
Fitzroy
March
Bagot
White L.
Pakenham
Huntley
Blithfield
Darling
Ramsay
ALMONTE
Goulbourn
North Canonto
LANARK
CARLETON PLACE
South Canonto
Lavant
Lanark
Mississippi L.
Beckwith
Marlborough
Dalhousie
Lanark
Drummond
Montague
45°
Palmerston
Bathurst
Perth
Smith's Falls
Big Gull Lake
Sharbot Lake
N. Elmsley
S. Elmsley
Wolford
Olden
Oso
S. Sherbrooke
Rideau
N. Burgess
Kitley
Bolton L.
N. Crosby
LEEDS
Hinchinbrooke
Westport
Newboro
Bastard
Rear of Yonge
Elizabethtown
Bedford
S. Crosby
Yonge
0
10
20
km
80°
Burton
Ardbeg
Pointe au Baril
East Burpee
Shawanaga
Hagerman
Croft
Ahmic L.
Spence
Ferguson
McKellar
Carling
Nobel
McDougall
Parry Sound
PARRY SOUND
Christie
79°
Livingstone
Mc Clintock
Clyde
Eyre
Kawagama Lake
Havelock
Sherborne
Lake of Bays
Guilford
Harburn
Ridout
HALIBURTON
Stanhope
Dudley
Hindon
Dysart
Drag L.
Wilberforce
Minden
Haliburton
45°
Anson
Minden
Glamorgan
Longford
Mc Connell
Sheppard
80°
Gull L.
Phyllis
Temagami
Askin
Hartle
Burnaby
79°
McCarthy
Clement
Olive
Milne
Flett
Angus
Parkman
Mackelcan
Macbeth
Vogt
Torrington
Rathbun
Kelly
McNish
Pardo
Hobbs
Mc Callum
Sisk
Kenny
Gooderham
La Salle
Mc. Auslan
Wyse
Davis
Janes
Dana
Mc Williams
Mc Laren
Gladman
Osborne
Clarkson
Thistle
Hammell
Garrow
Poitras
Scadding
Street
Loughrin
Henry
Crerar
Gibbons
Bastedo
Fell
Lyman
Notman
Stewart
Lockhart
Jocko
Eddy
Tomiko
Awrey
Hagar
Ratter
Hugel
Badgerow
Field
Grant
Charlton
Blyth
Merrick
Mulock
French
Butler
Verner
Springer
Pedley
Beaucage
Widdifield
Phelps
Olrig
Mattawan
Appleby
Dunnet
Kirkpatrick
Caldwell
Cache Bay
NORTH BAY
STURGEON FALLS
Macpherson
Manitou Is.
West Ferris
Corbeil
Bonfield
LAKE NIPISSING
0
10
20
km

Figure 43.1. *Location map of study area in the Grenville Province.*

metasedimentary rocks of the Frontenac Terrane to the south from amphibolite–facies metasedimentary and metavolcanic rocks of the Sharbot Lake Terrane to the north; and the approximate position of the boundary could be inferred from existing geologic maps that included part of the boundary (Wolff 1985; Wilson and Dugas 1961; Reinhardt 1973); no detailed study of this boundary had been previously undertaken.

The character of the boundary varies considerably, and the following discussion describes each of three segments of the boundary; namely, the Tich-

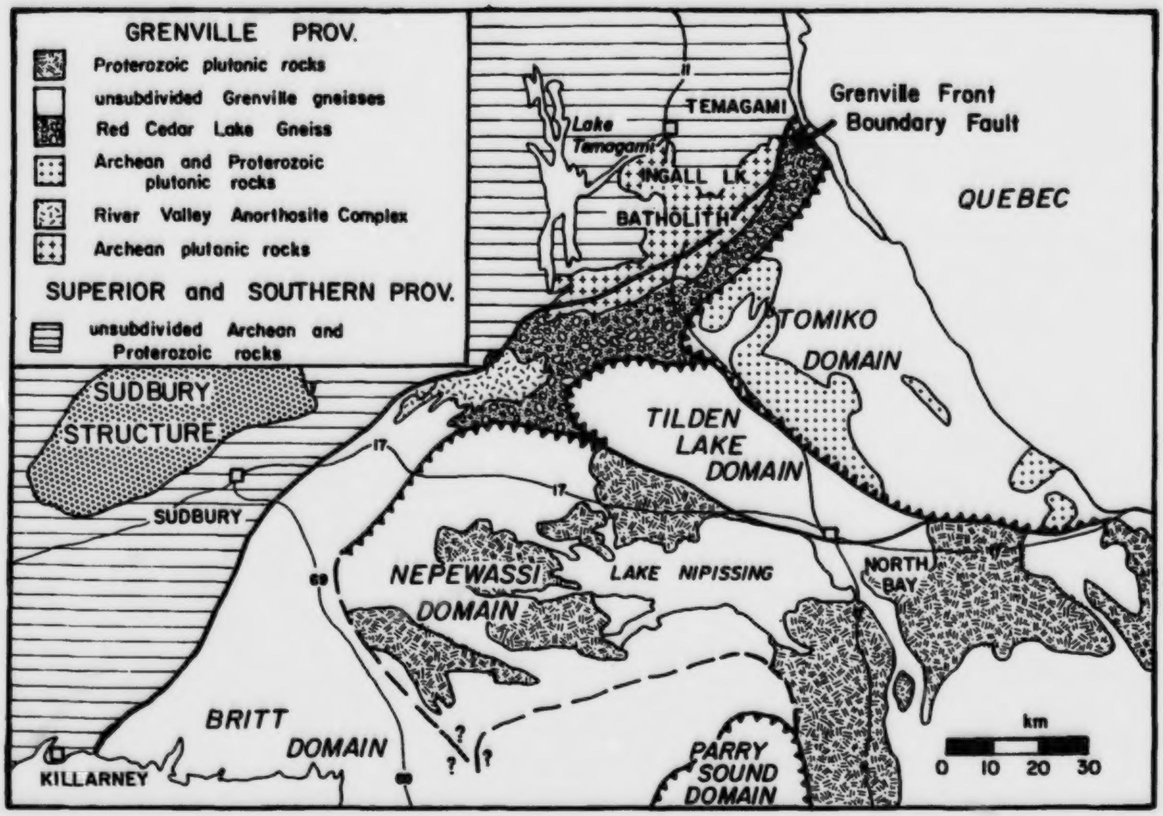
GRENVILLE PROV.
Proterozoic plutonic rocks
unsubdivided Grenville gneisses
Red Cedar Lake Gneiss
Archean and Proterozoic plutonic rocks
River Valley Anorthosite Complex
Archean plutonic rocks
SUPERIOR and SOUTHERN PROV.
unsubdivided Archean and Proterozoic rocks
11
TEMAGAMI
Lake Temagami
Grenville Front Boundary Fault
INGALL LK BATHOLITH
QUEBEC
TOMIKO DOMAIN
TILDEN LAKE DOMAIN
SUDBURY STRUCTURE
SUDBURY
17
17
69
NEPEWASSI DOMAIN
LAKE NIPISSING
NORTH BAY
BRITT DOMAIN
KILLARNEY
69
?
?
?
PARRY SOUND DOMAIN
km
0 10 20 30

Figure 43.2. *Distribution of the Red Cedar Lake Gneiss and probable lithotectonic domains in the northern Grenville Province in Ontario. Distribution of Red Cedar Lake Gneiss after Lumbers (1978).*

bourne–Sharbot Lake segment; the Maberly–Lanark segment, and the Carleton Place segment.

TICHBOURNE-SHARBOT LAKE SEGMENT

Between Tichbourne and Sharbot Lake, the boundary is marked by a north–trending, 250 to 300 m wide zone of mafic to intermediate straight and irregularly layered gneisses, that dip 60° to 70° to the east. These gneisses separate a zone of upper amphibolite–grade marble and quartzofeldspathic gneisses of the Sharbot Lake Terrane to the west from granulite–grade marbles, gabbros, and granitoid augen gneisses of the Frontenac Terrane to the east. These straight gneisses are well exposed on Highway 38 between Parham and Tichbourne. In the vicinity of Sharbot Lake, a number of late, weakly deformed granodiorites and monzogranites cut across the straight gneiss zone, obscuring the boundary, although, as to the south, it appears to be a narrow band of straight and irregular gneisses that separate two distinct lithological sequences. Northeast of Sharbot Lake, a series of layered amphibolitic rocks of the Sharbot Lake Terrane is juxtaposed against a package of augen gneisses and gabbroic to anorthositic rocks of the Lanark–Oso Gabbro Body. Here again, the zone of intense deformation characterized by the presence of straight and porphyroclastic gneisses seems to be no more than 250 m wide, dipping 60° to 70° to the east–southeast. Some of the layered amphibolites could be mistaken for straight gneisses, but similar rocks occur well to the west of the boundary in the Sharbot Lake Terrane, and as inclusions in the Lavant Gabbro Complex, suggesting that these rocks were layered before development of the Frontenac–Sharbot Lake Terrane boundary.

As noted by Wolff (1985), in the area between Sharbot Lake and Maberly, a number of fine– to medium–grained granodiorite to monzogranite bodies have intruded the Frontenac–Sharbot Lake Terrane boundary in a 1 to 2 km wide swath. These granitoid rocks appear to be less deformed than other rocks in the boundary zone; they cut across the straight gneisses, and are probably syn– to slightly post–tectonic.

MABERLY-LANARK SEGMENT

In the Maberly–Lanark segment, the Frontenac Terrane side of the boundary zone consists of a package of augen gneisses, marble breccia, diorites,

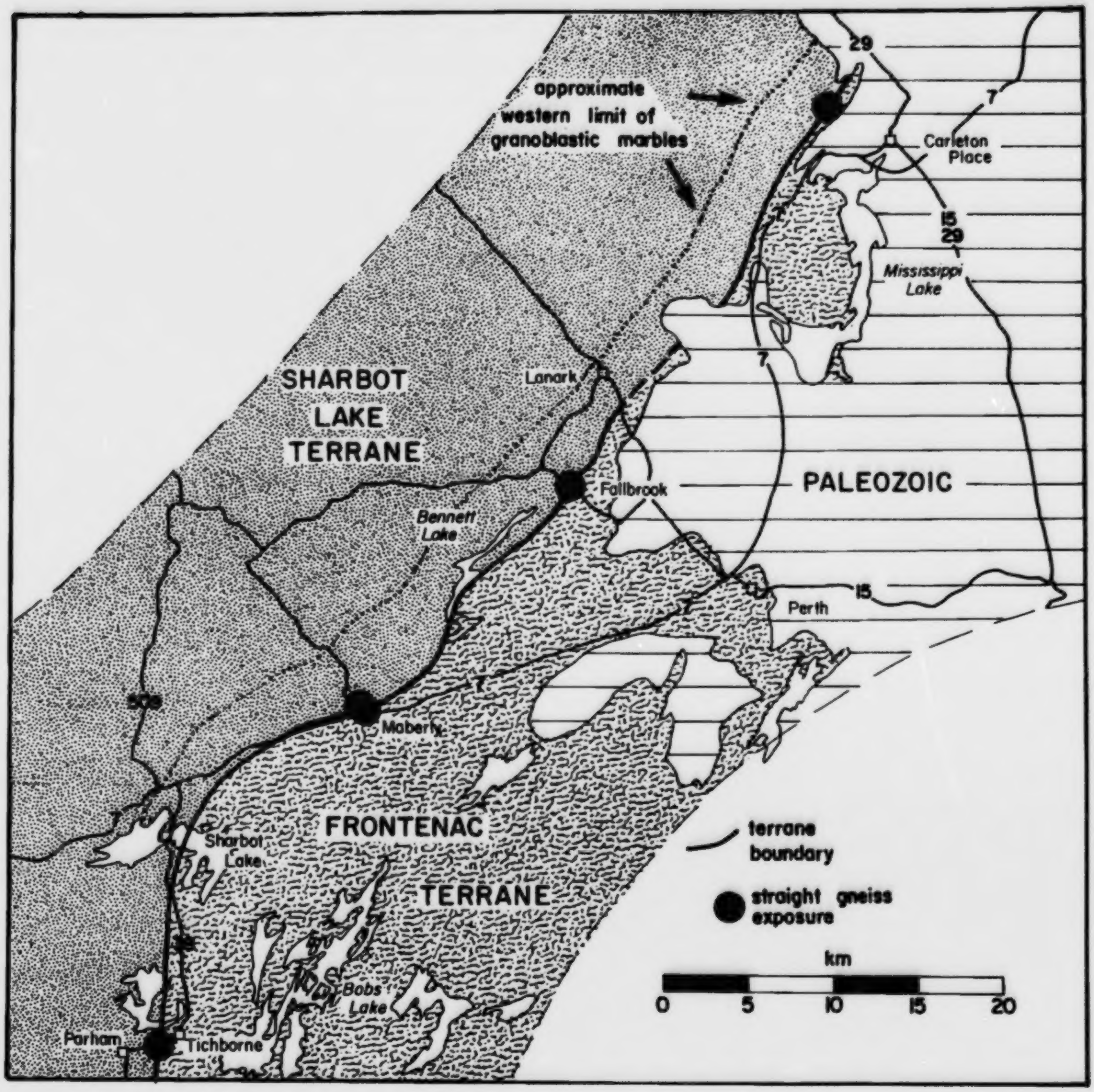
approximate western limit of granoblastic marbles
29
7
Carleton Place
15
29
Mississippi Lake
SHARBOT LAKE TERRANE
Lanark
7
Fallbrook
PALEOZOIC
Bennett Lake
15
Perth
509
Maberly
7
FRONTENAC TERRANE
Sharbot Lake
terrane boundary
straight gneiss exposure
km
0
5
10
15
20
Bobs Lake
Parham
Tichborne

Figure 43.3. *Frontenac–Sharbot Lake Terrane Boundary between Tichbourne and Carleton Place, Grenville Province, eastern Ontario.*

and quartzofeldspathic to quartzitic paragneisses, preserving granulite–facies assemblages. The Sharbot Lake Terrane side of the boundary zone consists mainly of calcitic marbles, with a few thin bands of rusty–weathering metasedimentary gneisses present locally near the contact with the Frontenac Terrane.

The boundary zone is only exposed at Maberly and at Fallbrook in this segment. At Maberly, straight gneisses are exposed both in Maberly and on Highway 7. The straight gneisses are mafic to intermediate in composition, and locally contain rounded blocks of less–deformed anorthosite, gabbroic anorthosite, and gabbro. These blocks are best observed in the outcrop in Maberly. The straight gneiss zone is only about 250 m wide, and seems to be derived mainly from rocks of the Frontenac Terrane. In Maberly, the straight gneisses of the boundary zone are in sharp (probably thrust–faulted) contact with rusty–weathering metasedimentary rocks of the Sharbot Lake Terrane along the Fall River.

Metamorphic and deformational effects apparently related to the boundary, extend several kilometres into the Sharbot Lake Terrane. About 3 km north of the contact, bedding and sedimentary features are preserved in marbles. As the boundary is approached, bedding is transposed into layering, and grain size increases. At 1 to 1.5 km from the contact, the marbles become massive, coarse-grained, and granoblastic. Secondary shear zones related to the boundary do not seem to carry far into the Sharbot Lake Terrane however, as a gabbro body located north of Maberly on Lanark County Road 12 only 500 m north of the boundary is undeformed, and does not contain any small-scale shears or other structural features that could be attributed to the boundary.

About 1 km east of McGowan Lake on Highway 7 (UTM 18T, E383050, N4967025), in an area of the Frontenac Terrane underlain by a mixture of marble, tectonic breccia, and more massive marble, is a band of almost pure, massive, white diopside, about 1.5 m wide, exposed over an outcrop length of 20 M. Identification of this material has been confirmed by X-ray diffraction at the Geoscience Laboratories, Ontario Geological Survey. Diopside is a valuable industrial mineral; a source of fibrous rock material that can be used in plastics, cements, and refractory products. Diopside is mined in Quebec near Wakefield (Easton et al. 1986); there is no producer in Ontario.

CARLETON PLACE SEGMENT

Between Lanark and Carleton Place, the boundary again changes. Here it runs through a wide band of marbles, and because of poor exposure, it is difficult to precisely define the boundary, although it is probably no more than 250 to 500 m wide. On Ramsay Township Concession Road 6 (UTM 18T, E406000, N500975), mafic and felsic straight gneisses, and a small granitic augen gneiss unit are exposed along the trace of the boundary. The mafic straight gneiss may be derived from gabbroic and amphibolitic rocks of the Sharbot Lake Terrane, and the augen gneiss resembles the augen gneisses found along the boundary between Maberly and Lanark. Within the Sharbot Lake Terrane, bedding in the marbles is well preserved 2 to 3 m north of the boundary. As the boundary is approached, bedding in the marbles is transposed into a weak layering, grain size increases, and within 1 km of the boundary, the marbles are massive and granoblastic. In the amphibolites, relict gabbroic textures gradually become obliterated toward the boundary, and layering becomes more prominent. Marbles on the Frontenac side of the boundary are more graphitic and phlogopitic than those present to the north, and are interbedded with quartz arenites and quartzofeldspathic gneisses, both of which are absent north of the boundary.

SUMMARY

As the result of this study, a few general statements can be made about the Frontenac-Sharbot Lake Terrane boundary:

1. The boundary with the Sharbot Lake Terrane is sharp, and deformation along the contact is mainly restricted to a zone roughly 250 m wide. This zone consists of straight and irregular gneisses (annealed mylonites).
2. Metamorphic effects cross the zone, and may extend several kilometres into the Sharbot Lake Terrane. Granulite-facies metamorphism seems to be contained mainly in the Frontenac Terrane. This may indicate the boundary developed prior to peak metamorphism.
3. The boundary juxtaposes two distinct lithological sequences.
4. Locally, the zone is cut by syn- to post-tectonic granitic intrusions.
5. At present, no lithologies can be correlated across the boundary.

EXTENSION OF THE ROBERTSON LAKE MYLONITE ZONE

Smith (1958) initially defined the Robertson Lake Shear Zone as a deformation zone present near Robertson Lake in eastern Ontario. Subsequent workers, notably Jackson (1980), Carter (1981), and Pauk (1984a, 1984b) extended this zone to the north and south of Robertson Lake, and documented several copper-gold-antimony occurrences along the zone. Easton and deKemp (1987) traced the zone further north to White Lake, and renamed the zone the Robertson Lake Mylonite Zone (RLMZ), reflecting the presence of proto- and ultramylonites along the zone which were unaffected by Grenvillian metamorphism. About one week was spent tracing the RLMZ north to the Quebec border, and south from Dalhousie Lake to Highway 7 and to the Paleozoic unconformity (Figure 43.4). Extensive assay sampling was also conducted along part of the zone in an attempt to determine if mineralization was localized in the Robertson-White Lake area, or if it extended along the zone.

WHITE LAKE-ARNPRIOR AREA

Although not exposed on Highway 417 north of Arnprior, the effects of the Robertson Lake Mylonite Zone are readily observed. Between Arnprior and Scheel Road (8 km west of Arnprior), several outcrops expose medium-grained, grey, bedded calcitic marbles typical of the Sharbot Lake Terrane. The grain size and preservation of bedding suggest that these marbles are at upper greenschist to lower amphibolite grade. Folding of the marbles increases to the west along the Highway, and near the Scheel Road/Highway 417 junction (UTM 18T, E386350, N503245), bedding becomes less distinct. The next outcrop west of this junction along the highway (UTM 18T, E384990, N5032925) consists of coarse-grained, weakly layered dolomitic and calcitic marbles, cut by a series of 25 to 75 cm wide marble mylonite zones that dip to the southeast at

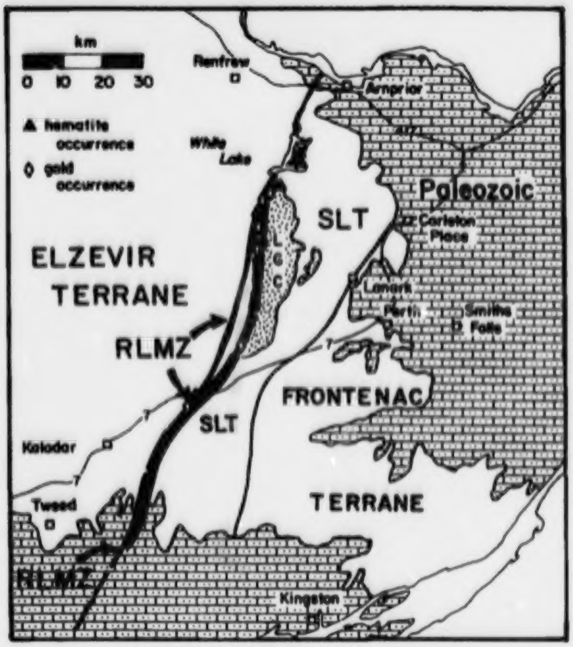

Figure 43.4. *Extent of the Robertson Lake Mylonite Zone (RLMZ) in eastern Ontario, showing known gold and hematite occurrences. Abbreviations: LGC – Lavant Gabbro Complex; SLT Sharbot Lake Terrane.*

about 30°, spaced at 2 to 3 m intervals. These mylonite zones are not present in outcrops further west, and the coarse-grained, layered nature of the marbles suggest upper amphibolite metamorphic grade. These mylonites are probably subsidiary to the main RLMZ, which probably lies in the creek valley between this outcrop and Scheel Road. The dolomitic marbles in the outcrop may not be primary, but may have been dolomitized by fluids associated with the nearby Paleozoic cover rocks.

Although outcrop exposure in the area between White Lake and Arnprior is locally poor due to the presence of Champlain Sea deposits, sufficient outcrop exists to trace the RLMZ southwest from Scheel Road to Stewartville, and then south to White Lake. Throughout this area, the RLMZ is bounded on either side by marble; the marbles north of the zone being white, calcitic, coarse-grained, and relatively massive, those to the south being grey, medium-grained, and thinly to medium-bedded calcitic marbles.

DiPrisco (this volume) examined a number of historic hematite deposits that occur on the east shore of White Lake. These deposits lie due east of the RLMZ. Assay samples collected by the author from two of these deposits show considerable enrichment in zinc, and elevated levels of antimony (Samples 88RME-379, 88RME-380, Table 43.1). About 3 km to the south, in the Darling area, a gold occurrence on the west shore of Darling Long Lake is hosted in hematized dolomitic marbles (Easton and deKemp 1987). Logging roads established in the last nine months south of White Mountain along the RLMZ, have exposed tills rich in large, dolomitic boulders containing hematite-rimmed breccias and hematite stringers, similar to those present along the east shore of White Lake. Assay samples from outcrop and float along this road are locally enriched in gold and copper (Samples 88RME-409, 88RME-410, Table 43.1). In the Darling-White Lake area there appears to be an association of hematitization with the eastern flank of the RLMZ, hematization which has locally concentrated other elements as well. Sample 88RME-300 (Table 43.1) from the RLMZ on Highway 7, is also enriched in copper, and is associated with a possible pre-Paleozoic weathering zone. Thus, it appears that the RLMZ may have been a locus for weathering prior to deposition of Paleozoic strata in the area (Figure 43.4), weathering which locally concentrated existing mineralization. Mapping of such weathering may be a useful exploration tool.

HIGHWAY 7 AREA

The RLMZ is well defined in the Dalhousie Lake area (Pauk 1984b), but is less well defined south of the southern edge of the Lavant Gabbro Complex. Also, in this area, the Addington Pluton changes from south-trending to southwest-trending. Mapping revealed that the main part of the RLMZ continues trending almost due south in this area, intersecting Highway 7 about 1 km west of White Lake. Here, the RLMZ is characterized mainly by the presence of pyrite-bearing, blue-grey, cloudy, fine-grained dolomitic marbles and schistose mafic rocks. Samples collected from the zone in this area (Table 43.1) show local evidence of mineralization, with the highest values coming from areas which may have been affected by pre-Paleozoic weathering. South of Highway 7, the trace of the zone is not clearly defined at present, but the zone appears to split into several branches. Only the main branch of the RLMZ south of Highway 7 is shown on Figure 43.4.

GRENVILLE FRONT STUDIES

The Grenville Front was examined in the Killarney, Sudbury, River Valley, and Tomiko areas this summer as part of an Ar^{39}/Ar^{40} sampling program across the front. The nature of the Grenville Front in the Killarney area has been well documented by Davidson (1986), and van Breemen and Davidson (1988).

STRATIGRAPHIC STUDIES

Although not fully completed in 1988, a survey of stratigraphic nomenclature within the Grenville Province was begun in order to determine which

TABLE 43.1: ASSAY RESULTS FROM SELECTED SAMPLES FROM THE ROBERTSON LAKE MYLONITE ZONE. ANALYSES BY THE GEOSCIENCE LABORATORIES, ONTARIO GEOLOGICAL SURVEY, TORONTO.

Sample Number	UTM Coordinates	Au(ppb)	Cu(ppm)	Zn(ppm)	Other* (ppm)
Highway 7 Area					
88RME-297A	E357800, N4957500	9	74	30	0.1 Sb
88RME-297B	" " " "	<2	67	730	0.1 Sb, 27 Pb
88RME-298B	E359500, N4957400	2	70	37	86 Co
88RME-300A	E359775, N4957600	19	545	22	3.5 Ag, 81 Ni
88RME-300B	" " " "	2	550	14	
88RME-300C	" " " "	5	585	14	225 Ni, 80 Pb
88RME-300E	" " " "	6	920	22	180 Co, 280 Ni
88RME-300F	" " " "	290			
88RME-300G	" " " "	50			
88RME-356B	" " " "	14	70	78	0.6 Sb
White Lake Area					
88RME-379A	E381500, N5016150	2	21	2380	25 Sb
88RME-379B	" " " "	2	<5	<10	0.2 Sb
88RME-380A	E381400, N5015025	2	9	4175	1 Sb
88RME-380B	" " " "	2	49	3950	9 Sb, 35 Pb
88RME-380C	" " " "	2	9	2030	4 Sb, 26 Pb
88RME-380D	" " " "	5	10	4980	9 Sb, 61 Pb
Darling Area					
88RME-409A	E372500, N5002100	<2	15	26	
88RME-409B	" " " "	<2	<5	71	136 Ni
88RME-409C	" " " "	<2	<5	12	
88RME-409D	" " " "	155	<5	<10	
88RME-409E	" " " "	<2	81	30	
88RME-410	E372000, N5003300	<2	198	55	74 Ni

**Other elements represent abundances at or above detection limits of 0.1 ppm for Sb, 5 ppm for Ni, 10 ppm for Pb, 0.3 ppm Ag, 5 ppm Co. Detection limit for Au is 2 ppb, <5 ppm for Cu, and <10 ppm for Zn. Background levels in area are generally close to detection limits.*

stratigraphic terms were worth retaining (or needed revision or abandonment) for use in the Geology of Ontario project and to produce a lexicon of formal stratigraphic terms in use in the Grenville Province in Ontario.

GOLD MINERALIZATION WITHIN THE GRENVILLE PROVINCE

Historically, three main types of gold mineralization have been noted in the Grenville Province in Ontario:

1. gold in quartz/carbonate veins near the greenschist/amphibolite metamorphic transition in the Elzevir Terrane in the Madoc area
2. gold in quartz/carbonate veins associated with the Flinton Group in the Elzevir Terrane in the Kaladar–Plevna area,
3. gold associated with copper and antimony in the Robertson Lake Mylonite Zone in the Lavant–Darling area.

Visits to the New Calumet gold deposit in Quebec, adjacent to the Ontario border and the Archean Hemlo deposits, suggest that potential exists for other types of gold mineralization in the Central Metasedimentary Belt in Ontario. These two other types of gold mineralization are described briefly below.

4. Gold associated with high–grade metavolcanic rocks and massive sulphide deposits — the New Calumet gold deposit (Villeneuve 1987), located on Grande Isle de Calumet in the Ottawa River in Quebec, occurs structurally below the Calumet zinc–lead–silver massive sulphide deposit, and is hosted by a garnet–cordierite–rich amphibolite. The deposit lies near the interface between volcanic and carbonate rocks in the area, and a variety of volcaniclastic rocks are present near this transition. The setting of the deposit is similar to the Mountauban Deposit, located further east in the Central Metasedimentary Belt in Quebec (Gauthier *et al.* 1985, Jourdain *et al.* 1987). Rocks similar to those hosting the Calumet Island Deposit are found in the easternmost Elzevir Terrane in Ontario in the area between Plevna and Renfrew. Much of this area has not been mapped in detail. Exploration for this type of gold association in Ontario should focus on the volcanic/carbonate rock interface near the

upper part of the volcanic succession, and in areas where known massive sulphide deposits have been reported (e.g. the Blithfield Pyrite Mine in the Darling area (Easton and deKemp 1987)).

5. Gold associated with volcaniclastic metasedimentary rocks — several days were spent examining the Archean Hemlo deposit near Marathon with Tom Muir of the Ontario Geological Survey. The Hemlo gold deposits are hosted in a series of deformed, intermediate to felsic volcaniclastic to pyroclastic rocks that are lithologically identical to the Apsley Formation of the Central Metasedimentary Belt (Easton 1986). South of the Hemlo Fault, a sequence of mafic and intermediate to felsic volcanic and volcaniclastic rocks is found which is similar to the "hornblende-rich metasediments" common in many Grenville volcanic sequences, particularly at the volcanic/sediment interface. A variety of factors control gold mineralization in the Hemlo Camp, most importantly specific deformation events as well as lithology (*see* Muir, this volume). Although similar volcano-sedimentary environments are present in the Grenville Province, it is not yet clear that similar deformation conditions existed. Thus, it remains to be seen if potential exists for similar types of mineralization in the Grenville Province. At present, exploration should focus on areas in the Grenville where volcaniclastic rocks are found in conjunction with deformation zones.

Easton (1986) suggested that the volcaniclastic rocks of the Apsley Formation had potential for gold mineralization, albeit for other reasons.

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44. Project Number 88–11. Geology of the Manitouwabing Lake Area, District of Parry Sound

G.D. McRoberts[1], R.I. Macfie[2], and D.J. Hammar[3]

[1]Geologist, Precambrian Geology Section, Ontario Geological Survey, Toronto.

[2]Graduate student, Queen's University, Kingston, Ontario.

[3]Student, Queen's University, Kingston, Ontario.

INTRODUCTION

The Manitouwabing Lake area is located approximately 3 km northeast of the town of Parry Sound and includes parts of Ferguson, McDougall, McKellar, Christie, and Spence townships. The map area (Figure 44.1) is bounded by Latitudes 45°22′30″N and 45°30′N and by Longitudes 79°45′W and 80°00′W. Field investigations in 1988 represent the southward extension of geological mapping at a scale of 1:15 840 that began in 1986 (Bright 1986; McRoberts and Tremblay 1988).

The map area is underlain by Middle Proterozoic rocks of the Central Gneiss Belt of the Grenville Province. Metamorphosed supracrustal rocks and mafic to felsic intrusive rocks are the most common lithologies that occur in the area of investigation.

Access to the area is provided by Highway 124, which transects the northwestern part of the map area, and by Highway 518 which transects the southeastern corner. Additional access is provided by township and cottage roads and by all–terrain vehicle trails.

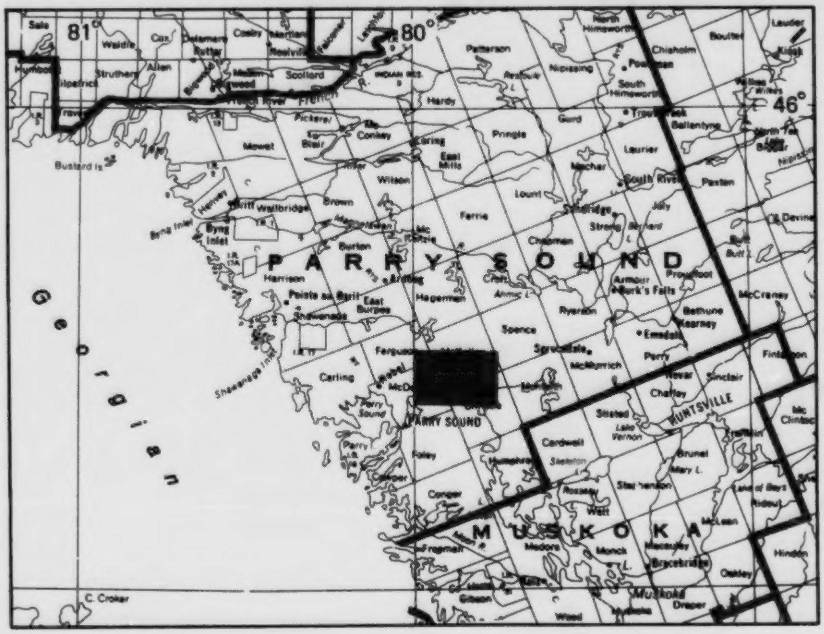

Figure 44.1. *Location map for the Manitouwabing Lake area, District of Parry Sound. Scale: 1:1 584 000 or 1 inch to 25 miles.*

This project A.2.1. is part of the five year Canada–Ontario 1985 Mineral Development Agreement (COMDA), a subsidiary agreement to the Economic and Regional Development Agreement (ERDA) signed by the governments of Canada and Ontario.

MINERAL EXPLORATION

Mineral exploration and production in the Parry Sound area dates back to the late nineteenth century. In 1894, the Oak Ridge Mine (Concession 12, lot 8, McDougall Township) opened and produced a small quantity of mottled white mica from granitoid pegmatite (Hewitt 1967). In the same year and continuing into the 1920s, several pits were opened in pegmatites in McDougall Township with no production having been reported. These include pits at the Valentine Mine (Concession 10, lot 12) in 1894; in Concession 10, lot 5 in 1926; and in Concession 12, lot 12 and Concession 11, lot 3 (Hewitt 1967). These showings have received no attention since then.

The McKellar Deposit (Concession 6, lot 4, McKellar Township) was worked during 1937 and 1938 with 600 tons of Number 1 grade feldspar produced from granitoid pegmatite and sold to Bathurst Feldspar Mines Limited (Hewitt 1967).

Minor molybdenite is reported at the Alfred H. Bloor, Deposit (Concession 12, lot 9, Christie Township). The deposit consists of several pits within marble (Hewitt 1967).

There is no record of recent exploration in the area in the Assessment Files Research Office, Ontario Geological Survey, Toronto (AFRO) or at the Resident Geologist's Office, Ministry of Northern Development and Mines, Dorset.

GENERAL GEOLOGY

INTRODUCTION

The Manitouwabing Lake area is underlain by Precambrian rocks of Middle Proterozoic age which form part of the Central Gneiss Belt of the Grenville Province. The map area is located 14 km south of the Whitestone Lake area mapped by Bright (1986).

The Manitouwabing Lake area lies within the Parry Sound Domain and is characterized by a group of older rocks consisting of metagabbro, marble breccia, paragneiss, and quartzofeldspathic gneiss of indeterminate origin intruded successively by metadiorite, metagranite, metagabbro dikes, granitoid pegmatite, and a diabase dike. Most of these rocks have been subjected to a protracted deformation history, and the degree of strain is varied. The metamorphic grade is predominantly granulite facies, except along the western side and in the southeastern corner of the map area where retrogressive amphibolite-facies mineral assemblages predominate. All rocks are metamorphosed except the granitoid pegmatites and diabase dike. Most rocks are migmatitic except for the Whitestone anorthosite body, the late metagabbro dikes, the pegmatites, and the diabase dike. Rocks in the southeastern corner of the map area are characterized by a higher amount of leucosome than most rocks in the map area.

OLDER ROCKS

Gabbroic rocks are the predominant lithology volumetrically in the western one third of the map area (Figure 44.2) and are interlayered at metre to hundred metre scales with other lithologies. In the central and eastern parts of the map area, gabbroic rocks form bodies and belts of varied size. Gabbroic rocks are fine to medium grained, massive to weakly foliated or lineated, or both, and consist of garnet–hornblende–pyroxene, hornblende–pyroxene, garnet–hornblende, and hornblende leucocratic, mesocratic, and melanocratic gabbro. Ultramafic rocks are rare while two generations of gabbro are locally present.

Fine–grained metagabbro locally is thinly interlayered with marble breccia and paragneiss and may have intruded as dikes or sills. However, not all gabbroic rocks necessarily intrude metasediments and those that do not may be earlier intrusions.

Marble tectonic breccia is characterized by 1 to 20 percent tectonically modified fragments of varied size in a medium– to coarse–grained calcitic matrix. Most fragments are gabbroic in composition. Interlayered calcitic and dolomitic marble occurs at the intersection between Highway 518 and the Seguin River.

Quartzofeldspathic gneisses of probable sedimentary protolith are minor and occur mainly in the western half of the map area (Figure 44.2) in association with marble breccia. They are leucocratic and are comprised mainly of quartz and feldspar with minor garnet, biotite, hornblende, pyroxene, sillimanite, and graphite.

Quartzofeldspathic gneisses of indeterminate origin occur locally in the eastern part of the map area (Figure 44.2), spatially associated with metagabbro and are comprised mainly of quartz and feldspar with minor biotite and hornblende. These gneisses are in part quartz rich near the community of Broadbent and host small garnet–epidote (calc–silicate ?) pods north of the community of Orrville. Some or all of these gneisses may be derived from a sedimentary protolith.

Quartzofeldspathic gneisses of probable sedimentary protolith and those of indeterminate origin are distinctive from most granitic and dioritic rocks in being highly migmatitic with 10 to 50 percent thin to very thin quartz–feldspar leucosome layers. These rocks may have been migmatitic prior to emplacement of metadiorite as highly migmatitic quartzofeldspathic gneiss of indeterminate origin are surrounded by weakly migmatitic metadiorite at Sugar Lake and have sharp contacts with dioritic rock at Isabella Lake. At Blackwater Lake, layered gneiss of indeterminate origin containing mafic boudins is intruded by both metagranite and dikes of late metagabbro and suggests that the layered gneiss was migmatitic and deformed prior to granite mag-

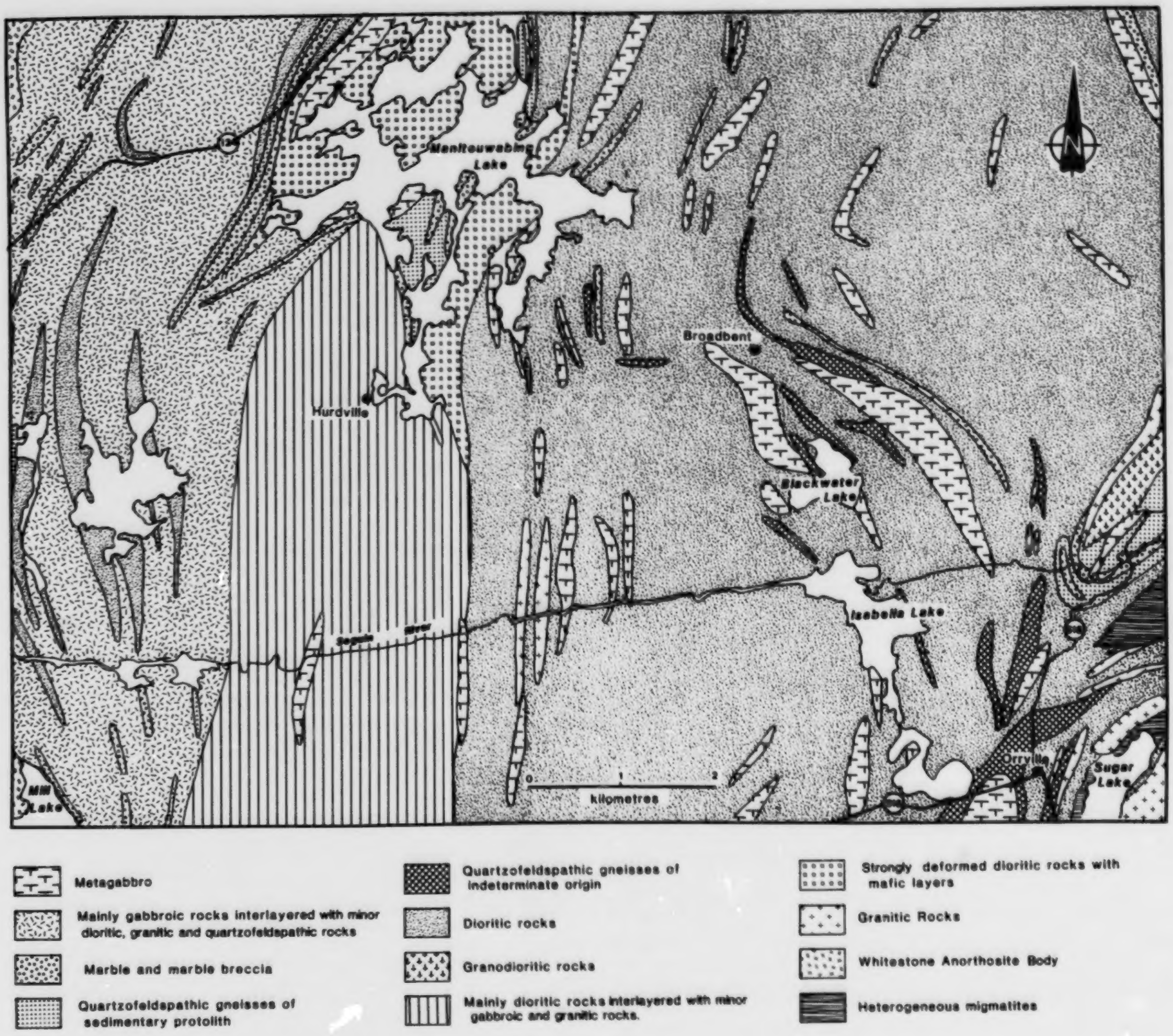
Manitouwabing Lake
Broadbent
Hurdville
Blackwater Lake
Isabella Lake
Seguin River
Orrville
Sugar Lake
Mill Lake
0
1
2
kilometres
Metagabbro
Mainly gabbroic rocks interlayered with minor dioritic, granitic and quartzofeldspathic rocks
Marble and marble breccia
Quartzofeldspathic gneisses of sedimentary protolith
Quartzofeldspathic gneisses of indeterminate origin
Dioritic rocks
Granodioritic rocks
Mainly dioritic rocks interlayered with minor gabbroic and granitic rocks.
Strongly deformed dioritic rocks with mafic layers
Granitic Rocks
Whitestone Anorthosite Body
Heterogeneous migmatites

Figure 44.2. *Generalized geological map of the Manitouwabing Lake area.*

matism. This gneiss may also have been intruded by older gabbroic rocks as marble and paragneiss have.

YOUNGER ROCKS

Rocks of the dioritic suite range in composition from tonalite to granite with diorite being predominant. Although occurring throughout the map area, they are volumetrically most abundant in the central and eastern parts (Figure 44.2). They intrude gabbroic rocks and commonly contain xenoliths of the older units. Intrusive relationships are preserved near the communities of Hurdville and Broadbent where dioritic veins emanating from metadiorite cut gabbroic rocks. Dioritic rocks with 10 to 70 percent xenoliths occur adjacent to metagabbroic bodies in the eastern part of the map area while those with less than 10 percent occur randomly. Layered dioritic and gabbroic rocks at Manitouwabing Lake (Figure 44.2) are interpreted as highly strained dioritic rocks containing gabbroic xenoliths and gabbroic layers. Dioritic rocks in the map area are correlated with the McKellar Gneiss north of the map area. An U–Pb age of intrusion of 1425±75 Ma has been reported for the McKellar Gneiss (van Breemen *et al.* 1986).

A distinctive pink to grey body of meta–quartz monzonite to granite–granodiorite occurs near Highway 518 and the eastern map boundary (Figure 44.2). Its relationship to the dioritic group of rocks is unclear. It is cut by metagranite.

Metagranite occurs as relatively narrow dike–like bodies throughout the map area. They are 5 cm to 30 m thick except in the southeastern corner where they are up to 100 m wide. A small part of an extensive tract of granitic rock south and southeast of the map area (Seguin Domain of Davidson *et al.* 1982) is exposed in the extreme southeastern corner of the map area. Metagranite is not found in the Whitestone anorthositic body and is probably older than it.

The Whitestone anorthositic body is exposed in the southwestern and northwestern corners of the map area and consists of two phases: an older leucocratic to mesocratic phase, and a younger anorthositic to gabbroic anorthosite phase. Subophitic and oikocrystic textures are widely preserved. It is not clear whether the Whitestone anorthositic body was tectonically or magmatically emplaced (with subsequent tectonic modification) into its present position. For the Whitestone body, van Breemen *et al.* (1986) report a U–Pb age of crystallization of 1350±50 Ma.

Thin metagabbro dikes occur locally throughout the map area and cut earlier gneissic layering at low angle in all rocks except the Whitestone anorthositic body. However, mafic dikes observed in the Arnstein and Raganooter Lake anorthositic bodies (McRoberts and Tremblay 1988) to the north likely belong to the same set of metagabbro dikes, and these locally cut foliation.

Granitoid pegmatites, locally foliated or disrupted, occur throughout the map area but are most common in areas completely or nearly completely retrogressed from granulite to amphibolite facies.

A diabase dike is exposed sporadically along the Seguin River and has contact–metamorphosed neighboring host rocks. The dike was intruded following regional metamorphism and tectonism and probably belongs to the group of east–trending diabase dikes known as the Grenville Dikes (Fahrig and West 1986) with a K–Ar age of emplacement of roughly 575 Ma.

STRUCTURAL GEOLOGY

Most rocks in the map area have been subjected to more than one period of deformation. The earliest deformation predates emplacement of dioritic and granitic rocks and is recognized at Isabella Lake where gneissic metagabbro xenoliths are hosted by nonfoliated metadiorite and at Blackwater Lake where metagranite cuts a more deformed quartzofeldspathic gneiss of indeterminate origin. The second period of deformation occurred prior to emplacement of mafic dikes and is recognized on the basis of massive to weakly foliated or lineated mafic dikes at an angle to gneissic layering in metagranites. The third, fourth, and fifth periods of deformation postdate emplacement of the mafic dikes.

The first period of deformation is characterized by transposition of leucosome and disruption of mafic layers at Blackwater Lake. The second period of deformation is characterized by a straightening of lithological contacts, flattening of metagabbroic xenoliths in metadiorite, and attenuation of mafic layers in metagranite. A fine foliation or lineation is not associated with either period of deformation and this may be the result of later mineralogical annealing.

Outcrop–scale isoclinal folds with steeply plunging fold axes are common in layered quartzofeldspathic gneisses and may be related to one or both of the early deformational events.

The third deformational event is commonly characterized by a fine mineral foliation, vague flattening of mafic clots and/or a fine stretching lineation. Lineation is southeast– to east–plunging where unaffected by later folding. The fine foliation is parallel to, or at an angle to earlier formed fabrics. More intensely deformed rocks are characterized by strong lineations, highly foliated to mylonitic zones, considerable straightening and thinning of compositional layering and disruption of pegmatites. Rocks intensely deformed during this period of deformation are widespread in the westernmost 20 percent of the map area and in the central part of the map area at Manitouwabing Lake (Figure 44.3) but also occur in relatively narrow zones elsewhere. This period of deformation is likely related chronologically to deformation preserved in the Parry Sound Shear Zone as both deformations disrupt and attenuate leucosome and pegmatites. Highly deformed rocks in the southwest corner of the map area are part of a package of rocks which includes rocks within the Parry Sound Shear Zone.

Mineral foliation and gneissic layering are generally northerly trending with oval structures present in the central and eastern parts of the map area (Figure 44.3). Heterogeneity in foliation trends are attributed to folding during the third deformational phase. Good road exposures reveal a spatial relationship between open to tight outcrop–scale folds and narrow shear zones. The shear zones predate the folding in one place and postdate it in another.

Oval and circular structures are the dominant megascopic feature in the map area and result from the variation in plunge of the fold axes of northerly trending folds. These structures, formed during the fourth period of deformation, fold the regional lineation resulting in local west–plunging lineations. One oval structure at Dell Lake is a basin and is similar to basins which occur sporadically throughout the western Central Gneiss Belt (Schwerdtner 1987). Several tight, upright antiformal and synformal structures in the map area may be related to this period of deformation.

Very narrow (1 mm to 1 cm wide) steeply dipping mylonite zones occur locally throughout the map area. They are at a high angle to the regional mineral foliation and the gneissic layering in contrast to wider mylonitic zones formed during the third period of deformation which parallel the regional fab-

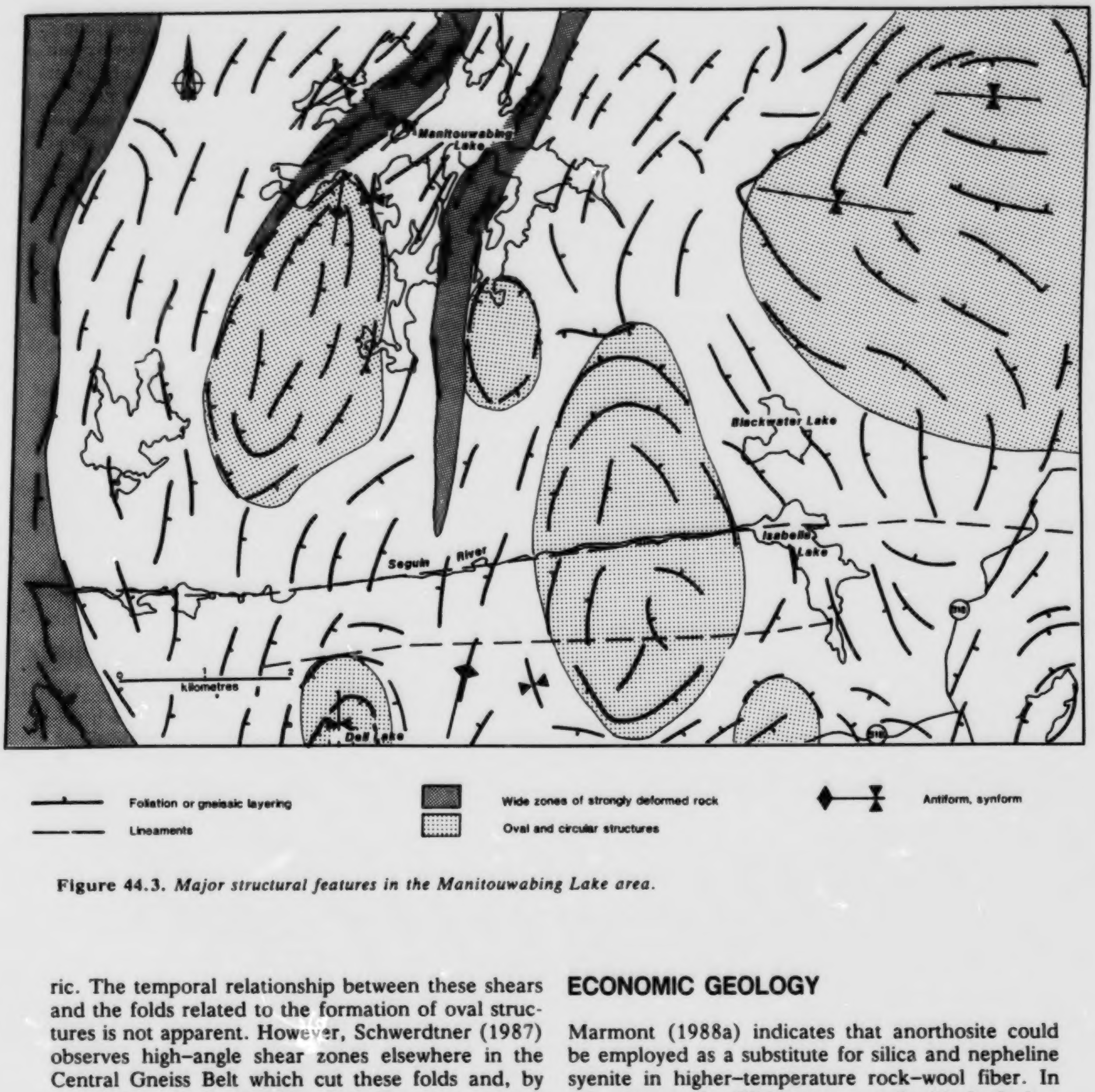
Manitouwabing Lake
Blackwater Lake
Isabella Lake
Seguin River
Dell Lake
0
1
2
kilometres
Foliation or gneissic layering
Lineaments
Wide zones of strongly deformed rock
Oval and circular structures
Antiform, synform

Figure 44.3. *Major structural features in the Manitouwabing Lake area.*

ric. The temporal relationship between these shears and the folds related to the formation of oval structures is not apparent. However, Schwerdtner (1987) observes high-angle shear zones elsewhere in the Central Gneiss Belt which cut these folds and, by correlation, it is possible that the very narrow mylonite zones postdate the folds. Similar structures elsewhere in the Central Gneiss Belt have been attributed to relaxation following northwest–directed thrusting (Davidson *et al.* 1985) or to late Proterozoic gravitational collapse of overthickened crust (Schwerdtner 1987).

Several east–trending lineaments in the map area may be either late joints or alternatively brittle faults similar to those present along the Georgian Bay coast as described by Culshaw *et al.* (1988). They have described displacements in the order of tens of metres.

ECONOMIC GEOLOGY

Marmont (1988a) indicates that anorthosite could be employed as a substitute for silica and nepheline syenite in higher–temperature rock–wool fiber. In this respect, the Whitestone anorthositic body is a favourable exploration target.

Marble found mainly as breccias represent a potential source of basic refractories and flux in the filler industry. In addition, Marmont (1988b) points out that the chemical composition of the marbles in the Parry Sound area is appropriate for neutralizing acidic soils and is thus suitable for agricultural purposes.

Metagabbroic rocks represent potential sources of platinum and palladium although sulphides were not observed in the map area. The western side of the Parry Sound Domain with high proportions of metagabbroic rocks is the most favourable exploration target for this type of mineralization.

Minor disseminated pyrite occurs rarely in rusty biotite–quartzofeldspathic gneiss, in thin quartzose or quartz–rich layers in metagabbro, and in fractures within metadiorite. Assay results for gold are still pending.

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45. Project Number 88–11. Preliminary Investigation of the Parry Sound–Seguin Domain Boundary

R.I. Macfie

Graduate Student, Department of Geological Sciences, University of Ottawa and Ottawa-Carleton Geoscience Centre, Ottawa, Ontario.

INTRODUCTION

During this past summer, about three weeks were spent carrying out a reconnaissance study, with selective detailed mapping, of part of the boundary between the Parry Sound Domain and the Seguin Subdomain of the Muskoka Domain (Davidson *et al.* 1982) (Figure 45.1). This work, performed while the author was employed as a field assistant by the Ontario Geological Survey (McRoberts *et al.*, this volume) and eventually forming part of the requirements of a Ph.D. Thesis at Queen's University under the supervision of John Dixon, provides new information on the nature of a previously poorly studied domain boundary within the western part of the Central Gneiss Belt.

REGIONAL GEOLOGY

Davidson *et al.* (1982) and Culshaw *et al.* (1983) recognized in the westernmost part of the Central Gneiss Belt "a number of lithotectonic regions, referred to as domains and subdomains, that are distinguished from one another by differences in their rock assemblages, internal structure, metamorphic grade and geophysical signatures" (Davidson 1986, p.63). Davidson and co-workers also identified deformation zones bounding and separating domains and subdomains. In places, these deformation zones yielded kinematic information, and a model involving "northwest-directed stacking of large blocks and slices along inclined ductile shear zones" (Davidson 1986, p.61) was proposed. Several of these slices are of direct interest here. These are the Parry Sound Domain and the Seguin, Rosseau, and Moon River subdomains of the Muskoka Domain.

Although the western margin of the Parry Sound Domain (the Parry Sound Shear Zone) is relatively well understood, (e.g. Nadeau 1984) the nature of the eastern margin of the Parry Sound Domain has not been well studied. The southern portion of this boundary, where it lies against the Sequin, Rosseau, and Moon River subdomains of the Muskoka Domain, forms the subject of this study. This report deals with a preliminary investigation of part of the boundary between the Parry Sound Domain and the Seguin Subdomain located near Orrville, and adjoins

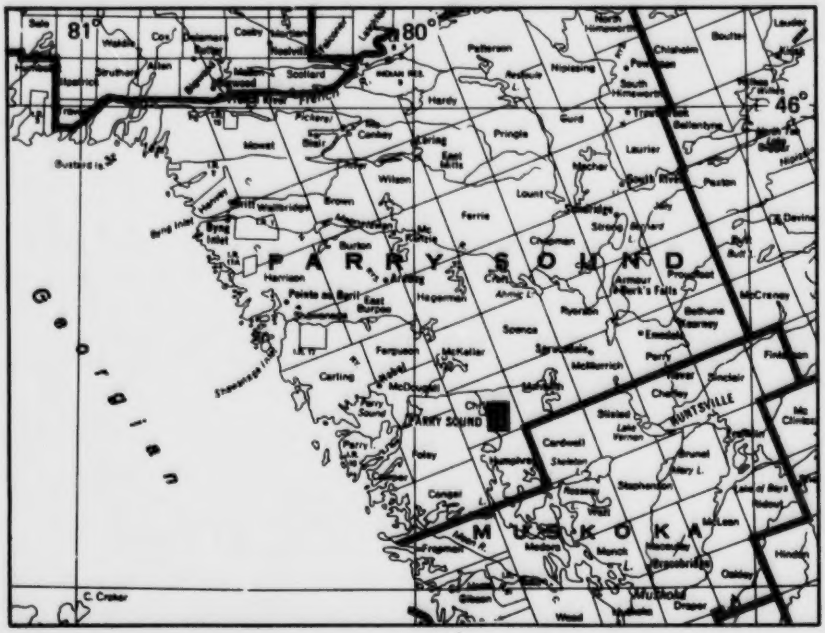

Figure 45.1. *Location map of the study area. Scale 1:1 584 000.*

the southeastern corner of the Manitouwabing Lake area mapped by McRoberts *et al.* (this volume).

GENERAL GEOLOGY

PARRY SOUND DOMAIN AND THE SEGUIN SUBDOMAIN

The Parry Sound Domain consists of "dark rocks–predominantly mafic and intermediate, layered, pyroxene–bearing gneisses with minor marble and other metasedimentary types, intruded by plutonic rocks ranging in composition from gabbro to granodiorite and all deformed together" (Davidson 1986, p.64). Ovoid bodies of dioritic to tonalitic rock show evidence of plutonic origin, and tectonized gabbro bodies occur in association with supracrustal rocks (McRoberts *et al.*, this volume; Davidson 1982). Most rocks of the Parry Sound Domain show evidence of granulite facies metamorphism, locally retrograded. Structural orientation is generally northerly, although deflected around the plutonic masses (Davidson *et al.* 1982; McRoberts *et al.*, this volume).

The Seguin Subdomain, on the other hand, is synformal with its major axis lying northwest, and consists mostly of lighter–coloured migmatite gneisses, many of tectonic origin (Davidson *et al.* 1982). This subdomain's metamorphic grade is predominantly amphibolite, although evidence of granulite facies metamorphism is found in places (Davidson *et al.* 1985). The Seguin Subdomain is thought to have been thrust onto the Parry Sound Domain, and a major deformation zone should lie between them. Published details relevant to the identification of the above domains and subdomains are found in Davidson *et al.* (1982) and Davidson (1986).

NEW OBSERVATIONS

The reconnaissance mapping of Davidson *et al.* (1982) placed the boundary between the Parry Sound Domain and the Seguin Subdomain in the general area of Orrville, Ontario (Figure 45.2).

Medium–grained dioritic to tonalitic hornblende orthogneisses, largely preserved at granulite facies and characteristic of the Parry Sound Domain, lying northwest of Orrville give way to Seguin–type amphibolite facies migmatitic and heterogeneous gneisses, mostly of unknown protolith, around, and to the east of, Orrville (Figure 45.2). As a package, these amphibolite grade gneisses are more leucocratic and more siliceous than the higher grade rocks to the west, and unlike those gneisses, are characterized by medium–grained sugary annealed textures with biotite as the dominant mafic mineral. The Seguin–type amphibolite grade terrane is richer in pegmatite and quartz veins, and noticeably poorer in amphibolite and metagabbro.

This lithological change is accompanied by a change in structural trends in the area which show a synclinal structural entrant in the east juxtaposed against a terrane having a predominantly northerly structural orientation (Figure 45.2). Although the location of the boundary is not readily apparent in the Orrville area, it does coincide more or less with a set of major lineaments truncating typical north–trending Parry Sound structural features and with lithological changes between the Parry Sound Domain and the Seguin Subdomain. However, no single, spectacular high strain zone, nor any major swarm of high strain zones, is present in the Orrville area. Kinematic indicators are rare and provide no consistent sense of tectonic transport direction.

Reconnaissance traversing from the Orrville area eastward into areas well within the Seguin Subdomain demonstrates that the migmatite gneisses of the Orrville area are continuous with similar rocks found well within the Seguin Subdomain, and share compositional, metamorphic, and structural characteristics with those rocks.

DISCUSSION

In the Orville area, the Parry Sound Domain–Seguin Subdomain boundary is characterized by the presence of highly deformed rocks. In places, Seguin–type migmatites, usually phlebitic, have straightened and sheared leucosome layers. Also present within this part of the Seguin Subdomain are fine– to medium–grained leucocratic and mesocratic gneisses of unknown protolith with only minor leucosome, which, although granular and annealed–looking at present, show textures characteristic of tectonities (c.f. Davidson *et al.* 1982). These include porphyroclasts derived from degradation of pegmatites, boudinaged layers, and straight layering and flattened leucosome layers. Parry Sound Domain rocks in the boundary area typically retain recognizable orthogneissic textures and show less evidence of pervasive deformation. High–strain zones do exist on the Parry Sound side, yet are narrow (metre–wide in scale) and generally retain evidence and textures characteristic of mylonitization.

A picture emerges of pervasively deformed amphibolite–facies migmatitic gneisses of the Seguin Subdomain lying adjacent to granulite facies orthogneisses which have been deformed mainly along narrow, discrete shear zones. Within the small area examined in detail during the past summer, the boundary is not sharply defined, and strongly deformed rocks are common both to the east and west of the presumed boundary. Further, although lithological packages on either side of the boundary area are compatible with the Parry Sound Domain and Seguin Subdomain as defined by Davidson *et al.* (1982), increasing amounts of migmatitic granitoid gneiss similar to that found in the Seguin Subdomain

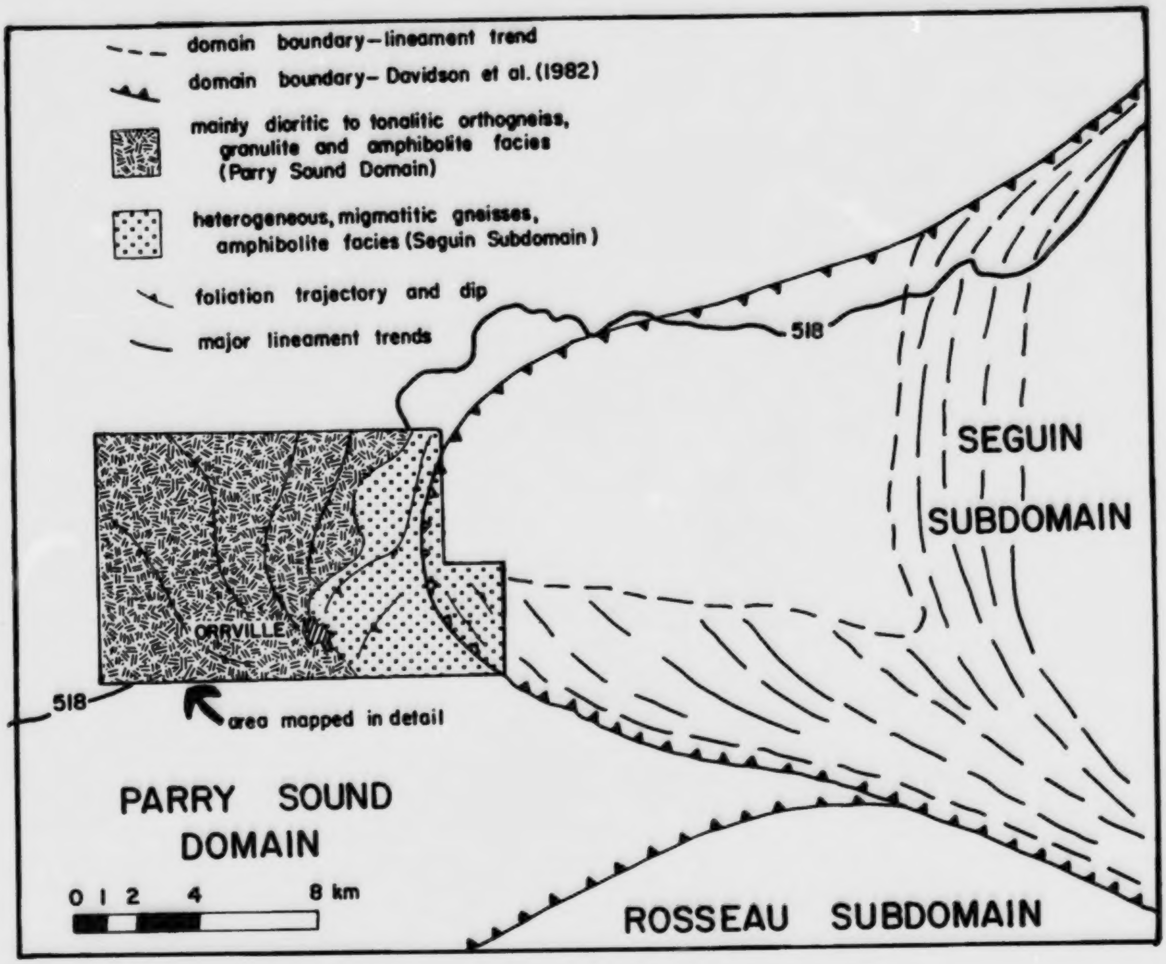
domain boundary–lineament trend
domain boundary– Davidson et al. (1982)
mainly dioritic to tonalitic orthogneiss, granulite and amphibolite facies (Parry Sound Domain)
heterogeneous, migmatitic gneisses, amphibolite facies (Seguin Subdomain)
foliation trajectory and dip
major lineament trends
518
518
ORRVILLE
area mapped in detail
SEGUIN SUBDOMAIN
PARRY SOUND DOMAIN
ROSSEAU SUBDOMAIN
0 1 2 4 8 km

Figure 45.2. *Geologic sketch map of the Orville area showing the location of domain boundaries and the area studied in detail.*

is observed in the Parry Sound Domain as the boundary is approached, hence, the lithologic distinction between the two lithotectonic domains is not absolute (*see* McRoberts *et al.*, this volume).

Comprehensive detailed mapping is needed along the Parry Sound Domain–Seguin Subdomain boundary if the boundary is to be properly delineated and the geologic and tectonic history of the Parry Sound area is to be properly understood. One interesting feature requiring further investigation is the pattern of lineament trends within the western part of the Seguin Subdomain (Figure 45.2). Spectacular lineaments, clearly tectonic in origin, suggest a peculiar and irregular contact (compared to other domain boundaries in the area) between the Parry Sound Domain and the Seguin Subdomain. Perhaps this is the result of erosion piercing a flat–lying portion of the overthrust Seguin Subdomain to expose the underlying Parry Sound Domain.

SUMMARY

The limited field work done to date has shed new light on the nature of the Parry Sound Domain–Seguin Subdomain boundary; namely, the lithologic changes that occur across this boundary are subtle, and a specific bounding deformation zone cannot be identified. The exact location of the boundary (insofar as it may be represented by a line on a map) is therefore difficult to pinpoint. Mapping of the boundary northeast and southeast of Orrville is needed in order to better define the lithologic and metamorphic contrast between the Parry Sound Domain and the Seguin Subdomain. Also, the area southeast of Orrville where the Parry Sound domain and the Rosseau and Seguin subdomains are in mutual contact needs to be studied in detail.

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46. Industrial Minerals, Rare–earth Elements, and Building Stone in the Districts of Muskoka, Parry Sound, and Nipissing, and the County of Haliburton

C. Marmont, P.M. Zuberec, and W.D. Conrod

Geologists, Ontario Ministry of Northern Development and Mines, Dorset.

INTRODUCTION

This report summarizes field work undertaken during the third year of a three–year project to evaluate the industrial mineral potential of the Muskoka–Parry Sound–Nipissing area (Figure 46.1). The results of the first two years of work were reported by Marmont and Johnston (1987), and Marmont (1988a, 1988b, in preparation). Work performed during the 1988 field season concentrated on feldspar and building stone. Work on feldspar was directed primarily toward high calcium – high aluminum feldspar in anorthositic intrusive rocks, which have potential applications in the fabrication of glass, ceramics, insulation materials (mineral wool), and in the filler industry. In the case of building stone, the focus has been upon the evaluation of banded gneisses suitable for the production of thin veneer panels and tiles for floor and wall coverings. Some pegmatites have been investigated as possible sources of quartz, feldspar, and rare–earth elements. The results of this year's work will be reported more fully in an Open File Report in 1989 (Marmont, in preparation).

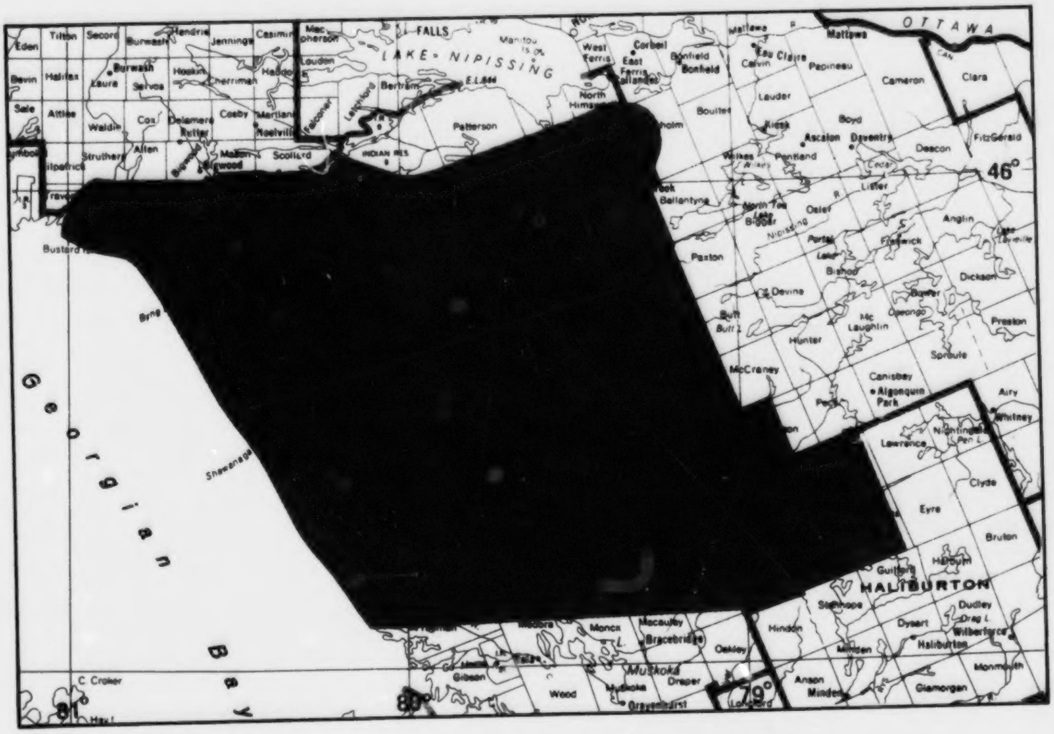


Figure 46.1. *Location map for the study area. Scale: 1:1 584 000 or 1 inch to 25 miles.*

This project A.2.4 is part of the five year Canada–Ontario 1985 Mineral Development Agreement (COMDA), a subsidiary agreement to the Economic and Regional Development Agreement (ERDA) signed by the governments of Canada and Ontario.

MINERAL EXPLORATION

The history of mining and mineral exploration in the study area has been described by Marmont and Johnston (1987). Local activity in the industrial minerals field is focused mainly on graphite (Garland 1987a, 1987b). North Coast Industries is engaged in a feasibility study of its Maria Township crystalline flake graphite property, and Cal Graphite Corporation's flake graphite property in Butt Township is under development. Some interest has been expressed in using local marble as agricultural limestone. Cal Graphite Corporation may utilize local marble for tailings pond neutralization. Test pits have been opened on flagstone occurrences near Magnetawan and Dorset. Several mafic to ultramafic bodies are being explored for platinum (Garland 1987c).

GENERAL GEOLOGY

The study area is located in the Central Gneiss Belt of the Grenville Province (Moore *et al.* 1986). It is a structurally complex area of ortho– and paragneisses metamorphosed to upper amphibolite and granulite facies. A brief overview of the geology of the area is presented in Marmont and Johnston (1987). During 1988, mapping programs were conducted in the Parry Sound area of Georgian Bay by N.G. Culshaw of Dalhousie University, Halifax (a contribution to the Canada–Ontario Mineral Development Agreement), and east of Parry Sound by G.D. McRoberts of the Ontario Geological Survey (McRoberts and MacFie, this volume).

CURRENT PROGRAM

FELDSPAR

Industrial mineral operations are generally founded upon minerals or rock types possessing some unique physical and/or chemical characteristic(s). Industrial mineral deposits are commonly monomineralic, or contain minerals which can be cheaply mined and beneficiated. At present, there appears to be no major industrial operation which exploits the large volumes of almost monomineralic plagioclase feldspar found in anorthosite bodies. Such "lime" feldspar is high in calcium (12 percent CaO) and alumina (28 to 30 percent). In the past, anorthosites have been considered as possible sources of alumina, but they cannot compete with bauxite, of which there is currently an abundant supply. Lime feldspar would be an acceptable component in certain glass and ceramic applications, as well as in the mineral wool and filler industries. These currently use potash and/or soda spar derived from pegmatite, aplite and alaskite deposits, or nepheline syenite. It is unlikely that lime feldspar will make significant inroads into these well established markets in the near future. Development of anorthosite will probably depend upon the recognition of applications based on the peculiar chemical composition of its feldspar, or on physical characteristics such as its higher melting point. These are avenues of research which may warrant investigation.

Several large anorthosite bodies occur in the Parry Sound and Haliburton areas (Figure 46.2). Previous work (Marmont 1988a, 1988b) indicated that parts of the Whitestone and Moon River bodies consist of "clean" anorthosite containing less than 1 percent Fe_2O_3. The iron is contained mainly within clinopyroxene, amphibole, garnet, and magnetite–ilmenite which aggregate from 2 to 7 percent by volume of the cleaner anorthosite, depending upon the relative proportions of the iron–bearing minerals. All are minerals which can be readily separated by commercial electromagnetic methods.

It was also noted that some apparently very clean anorthosites (colour index less than 2) contain large amounts of silicate and oxide inclusions in the plagioclase, whereas others contain only minor inclusions. This property is likely to affect the recovery of a clean lime feldspar product during mineral dressing.

The colour of the feldspar and the amount of mineral inclusions within it are functions of recrystallization and grain size reduction produced during periods of ductile deformation: primary igneous feldspar is dark grey to black and replete with oxide inclusions, but upon recrystallization the inclusions are expelled and the feldspar becomes paler grey or white.

The field work performed during 1988 was directed towards determining the distribution of clean anorthosite within the several anorthositic to gabbroic bodies in the study area, and to determine which anorthosites contain mineral inclusions in the feldspar, which may adversely affect beneficiation in any future development.

Of the anorthosite bodies indicated in Figure 46.2, seven are of a size capable of containing potentially economic volumes of rock. In the Parry Sound area, these include the Moon River, Parry Island, Whitestone, Arnstein, and Raganooter bodies; and in the Haliburton area, the Allsaw and Percy Lake bodies. The remaining anorthosites form thin, commonly disrupted sheets, only a few metres or tens of metres thick. The bodies in the Parry Sound area probably have a bulk composition of gabbroic anorthosite (perhaps 15 to 20 percent mafic minerals), whereas the Allsaw and Percy Lake bodies consist predominantly of anorthosite with lesser amounts of more mafic material. Each body exhibits distinctive characteristics.

The Whitestone Anorthosite exhibits a crudely concentric zonation, being more mafic and increasingly deformed and retrograded towards the margins. Oikocrysts of clinopyroxene up to 0.3 m in diameter give the rock a characteristic leopard–spotted appearance in the dominantly gabbroic anor-

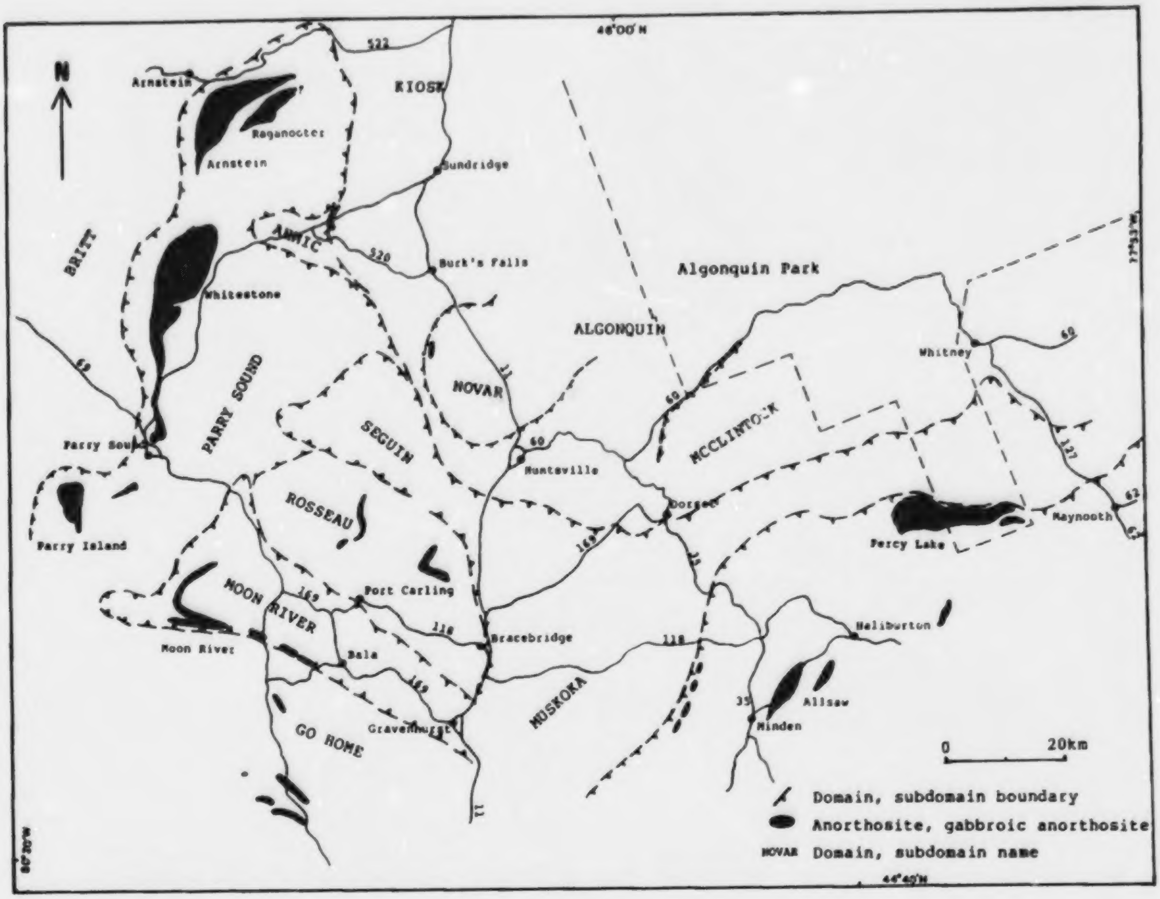

N
46°00'N
45°40'N
80°20'W
77°53'W
Arnstein
Raganooter
Whitestone
Parry Sound
Parry Island
Moon River
Sundridge
Burk's Falls
Huntsville
Port Carling
Bracebridge
Bala
Gravenhurst
Dorset
Haliburton
Allsaw
Minden
Whitney
Maynooth
Percy Lake
Algonquin Park
KIOSK
BRITT
AHMIC
PARRY SOUND
NOVAR
ALGONQUIN
SEGUIN
ROSSEAU
MOON RIVER
GO HOME
MUSKOKA
MCCLINTOCK
522
520
11
60
69
169
118
35
127
62
0
20km
Domain, subdomain boundary
Anorthosite, gabbroic anorthosite
NOVAR Domain, subdomain name

Figure 46.2. *Location of major anorthosite bodies in the Huntsville–Parry Sound–Haliburton Area.*

thosite body. Both primary and metamorphic orthopyroxene grains occur in the innermost facies. Remnant plagioclase crystals up to 8 cm long have been noted in the central areas, and are a darker colour than the usual pale grey to off-white colour of the recrystallized plagioclase which forms the greater part of the body. Several areas around Blue Lake contain fairly clean anorthosite with very low colour indices, but silicate and lesser oxide inclusions are abundant (Marmont 1988a).

The Arnstein Anorthosite is more deformed than the Whitestone. It is commonly gneissic, and bands of clean white anorthosite a few centimetres or tens of centimetres thick alternate with gabbro or amphibolite layers, which have a streaky, network or clotted texture. The net composition is probably gabbroic anorthosite. Most pyroxene has been retrograded to hornblende. No large areas with low colour indices were found. A band of material with a colour index of about 10 was roughly outlined in the east–central part of the body, and a possibly cleaner area noted on the northwestern side of the body southeast of Long Lake.

The Raganooter body consists largely of hornblende/pyroxene blastoporphyritic gabbroic anorthosite. Fine-grained garnet commonly rims the mafic minerals. Colour index measurements indicate a slightly less mafic composition than the gabbroic anorthosites of the Whitestone body. An area of about 0.5 km^2 just north of Raganooter Lake consists of protoclastic-textured anorthosite with a colour index of less than 5. Feldspars in this area are a purplish-brown colour, suggesting that they are less recrystallized than in other parts of the body and are likely to contain oxide mineral inclusions.

The Parry Island Anorthosite was examined on several small islands west of Parry Island. Excellent wave-washed exposure reveals a mixed assemblage of anorthosite, gabbroic anorthosite and garnetiferous gabbro and anorthositic gabbro. Of particular interest are remnant plagioclase crystals up to 25 cm in length and orthopyroxene megacrysts up to 50 cm in size. The plagioclase megacrysts are dark grey to black, set in a matrix of recrystallized pale grey to white plagioclase, and partially recrystallized feldspar of intermediate size and shades of grey. Orthopyroxene megacrysts can be seen in various stages of disaggregation and alteration, ultimately forming highly flattened lenses and wisps composed of clinopyroxene and/or hornblende. In places, a remnant core of orthopyroxene remains in these mafic clots. This evidence suggests that the hornblende-rich clots and streaks in more deformed bodies such as the Arnstein Anorthosite may well be derived from primary pyroxene megacrysts. It is speculated that further deformation may disaggregate these clots to produce parallel bands of disseminated hornblende and biotite such as are found in the Moon River Anorthosite and other, thin, highly attenuated anorthositic bodies.

The Moon River Anorthosite lies within the Moon River Subdomain (Davidson *et al.* 1982), whereas the four bodies described above lie within the Parry Sound Domain. The Moon River Anorthosite is mainly composed of gabbroic anorthosite, but has significant areas of clean white anorthosite with a colour index of less than 5. The body is characteristically layered on a centimetre to decimetre scale, with alternating bands of almost pure anorthosite (colour index less than 2) and anorthosite/gabbroic anorthosite with a colour index of 8 to 20. Biotite and hornblende are the major mafic minerals, with minor garnet, epidote, chlorite, and magnetite. The plagioclase is commonly sericitized and is free from inclusions other than a dusting of unidentified micron-sized particles.

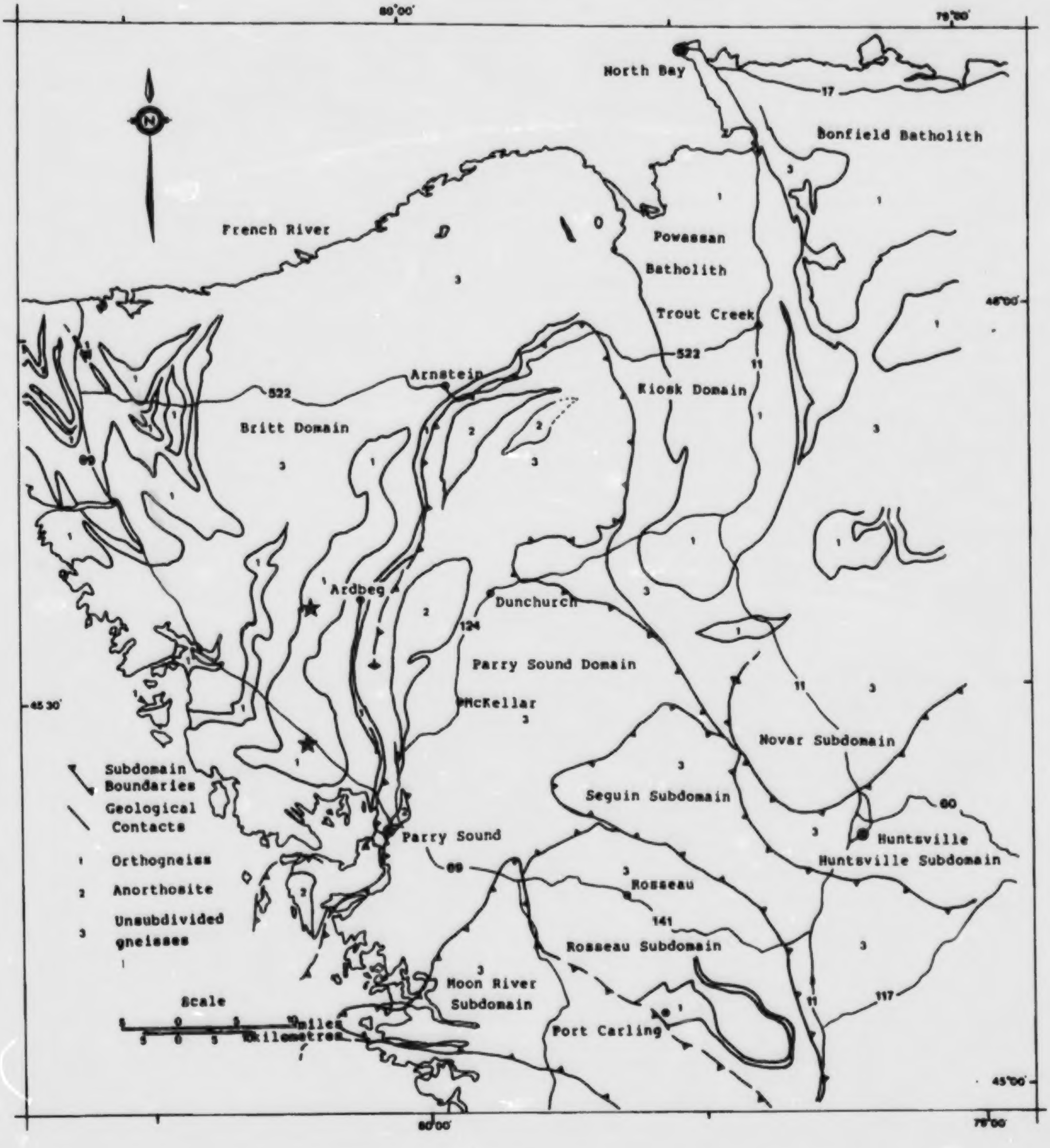
The Allsaw Anorthosite lies within the Central Metasedimentary Belt Boundary Zone, and is enveloped by a tectonic marble breccia (Easton 1987). It contains some gabbroic anorthosite, but is mostly a clean white anorthosite. Unfortunately, from a potential economic point of view, it is riddled with granitic pegmatite and carbonate veins (including possible carbonatitic material), which would likely complicate mineral dressing procedures and adversely affect the recovery of a lime-feldspar concentrate.

The Percy Lake Anorthosite is largely anorthositic, with lesser amounts of gabbroic anorthosite. The feldspar is very white, with biotite, hornblende, and muscovite erratically disseminated throughout, and forming weakly defined bands which dip gently to over 30° to the south. In only one location were good remnant plagioclase crystals noted, being up to 6 cm long and a medium-dark grey colour. Irregular, thin granitic pegmatite dikes can be found in most outcrops. Relief in the area is in the order of 60 to 80 m. At the base of almost all outcrops, and, to a lesser extent, within outcrops, there occur ductile shear zones, which range in thickness from 1 m to possibly as much as several tens of metres. The shears largely consist of granitic pegmatite material exhibiting various degrees of dissaggregation and comminution. The most deformed varieties are a medium-grained, pink, gneissic granite, containing small remnant potash feldspar crystals. Some shears contain an equigranular, medium-grained, pink granitic or monzonitic rock which may be either a distinct intrusive phase or a recrystallized, sheared pegmatite. Above the shears, the anorthosite commonly exhibits a lenticular structure on a scale of 0.3 to 1.0 m produced by millimetre- to centimetre-wide anastomosing shears of comminuted anorthosite. In places, rotated blocks of anorthosite can be discerned within a finer grained anorthosite matrix. This grades up into parallel-foliated anorthosite which in turn grades up into the regular massive white anorthosite. Locally, a sheared hornblende or biotite gneiss, sometimes containing disaggregated pegmatite and feldspar porphyroclasts, underlies the pegmatite. The presence of these numerous shear zones suggests that the body may be relatively thin, and that its outcrop width, from 1 to 3 km, may result from imbricate stacking of thrust slices. The pegmatitic and mafic shear zone material constitute perhaps 5 percent of the body by volume, which would have to be separated in any future attempt to recover a lime-feldspar concentrate.

At the time of writing, field work is continuing. Over the winter, samples will be analyzed, and petrographic studies undertaken in order to assess the purity of anorthosite in the various bodies described above, and to evaluate any adverse effects which the mineralogy and mineral inclusions might have on mineral dressing procedures. At the present time, it appears that relatively uniform areas of clean anorthosite occur in several of the anorthositic bodies in the Parry Sound and Haliburton areas. Because outcrop exposure is incomplete, and features such as scattered oikocrysts and mafic clots make representative surface sampling very difficult, proper assessment of the grade and volume of clean anorthosite will require "stratigraphic" drill programs and bulk core sampling.

BUILDING STONE

The building stone component of the project has focused on gneisses. The objective of the program is to determine whether gneisses exist comparable to those currently marketed by Brazil, India, and elsewhere as panels and tiles suitable for wall and floor coverings. Most attention has been directed to orthogneiss units delineated by Davidson *et al.* (1982) (Figure 46.3). The program, which is ongoing at the time of writing, consists of three parts: 1) reconnaissance: examination of roadside outcrops, and large outcrops within a short distance of the road identified from aerial photographs; 2) follow-up: detailed surveying of large outcrop areas which reconnaissance surveys indicated contained a low joint density, uniformity of lithology, grain size, texture, and colour, and which contain minimal amounts of deleterious minerals such as sulphides or seams of mica; and 3) extraction of small blocks (0.5 m by 0.5 m by 0.5 m) for sawing and polishing into twelve-inch tiles in order to assess their appearance and durability.


80°00'
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N
North Bay
17
Bonfield Batholith
French River
Powassan
Batholith
Trout Creek
522
Arnstein
Kiosk Domain
Britt Domain
69
11
Ardbeg
Dunchurch
124
Parry Sound Domain
McKellar
Novar Subdomain
Seguin Subdomain
60
Huntsville
Huntsville Subdomain
Parry Sound
Rosseau
141
Rosseau Subdomain
Moon River
Subdomain
Port Carling
117
Subdomain Boundaries
Geological Contacts
1 Orthogneiss
2 Anorthosite
3 Unsubdivided gneisses
Scale
Miles
Kilometres

Figure 46.3. *Orthogneiss units in the Huntsville–Parry Sound Area.*

The major constraint upon dimensional stone prospects is the density of joints and fractures. Most outcrops examined display three or four closely spaced joint sets, which preclude the possibility of extracting large quarry blocks. On the basis of work performed to date, two building stone prospects in the study area appear to have some potential as sources of dimensional stone (Figure 46.3). An area astride Highway 69 in Carling Township contains large exposures of gneiss which locally have only one or two joint sets at a low density (greater than 5 m). Access is good and the area is undeveloped. In Burton Township, west of Ardbeg, an area along the power lines is well exposed. It is moderately jointed (1.5 to 3.0 m), and lies in an undeveloped area. Both of these occurrences are migmatitic granodioritic gneisses, part of Davidson *et al.'s* (1982) orthogneiss unit 9 in the Britt Domain.

Small blocks will be extracted from these two sites in the fall of 1988 to test their sawing and polishing characteristics, and strength of the gneisses.

Similar migmatites also occur west of Rosseau in the Rosseau Subdomain. Locally, these appear to be only moderately jointed, and some may be candidates for the extraction of small blocks, but the gneisses are not as well exposed as those in Burton and Carling townships.

Many attractive rock types have been noted in the course of roadside reconnaissance, but the density of joints in all but a very few outcrops precludes the possibility of recovering quarry blocks of economic size. Some of these occurrences may be capable of sustaining small operations to supply material for monument stone, ashlar, or decorative stone. One example of such stone is the augen–textured biotite granodiorite found between Huntsville and Dwight (Lehman Quarry, Sinclair Township, concession 1, lot 18). Another attractive rock is flagstone of the type quarried at Mill Lake Quarry, Parry Sound. When cut perpendicular to the foliation planes (along which the rock splits readily) and polished, the resulting pattern resembles that of petrified wood, with knots represented by feldspar porphyroclasts. Mylonites with this texture can be found in many of the ductile shear zones shown on Figure 46.3. Obviously, the thinly splitting nature of the flagstones precludes their use as dimensional stone, but, locally, the distinctive ribbon lineation may be more widely spaced, permitting extraction of blocks suitable for monuments or decorative stone.

At the time of writing, reconnaissance work is continuing, with the objective of identifying additional sites suitable for extraction and testing during the late fall of 1988. This includes the examination of coronitic metagabbros previously described by Marmont and Johnston (1987).

PEGMATITE

Evaluation of pegmatites as a source of silica, feldspar, and rare–earth elements is continuing, but the small size of most bodies limits their economic potential.

ACKNOWLEDGMENTS

Mike Harris and Karen Haynes are thanked for their enthusiastic assistance in the field. S.B. Lumbers kindly provided a map showing the disposition of the Percy Lake Anorthosite which greatly facilitated the field work.

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47. Project Number 88–17. Remote Sensing Study of Curvilinear, Structural Features in the Parry Sound Domain, Grenville Province

M.L. Tremblay

Geologist, Precambrian Geology Section, Ontario Geological Survey, Toronto.

INTRODUCTION

The Parry Sound Domain forms part of the Central Gneiss Belt in the Grenville Province. It is located to the east of the town of Parry Sound, on Georgian Bay. Detailed mapping of the Parry Sound area was undertaken in 1986 by the Ontario Geological Survey (Bright 1986; McRoberts and Tremblay 1987; McRoberts *et al.*, this volume) in order to improve the available data on this domain of predominantly mafic to intermediate rocks. The intent of this study is to analyze the curvilinear, structural bedrock features from remote sensing images, and determine if the domain boundaries of the Parry Sound Domain (Davidson and Grant 1986) are visible from the lineament distribution. This could help target future mapping sites. A secondary goal of the study is to develop a quantitative technique enabling the objective analysis of curvilinear, structural features, and to compare the results with visual more subjective analysis. This project involved the collaboration of V. Singhroy and F. Kenny from the Ontario Centre for Remote Sensing, who offered technical equipment and support.

GENERAL GEOLOGY

The rocks of the Parry Sound Domain are Middle Proterozoic in age. They are interpreted to overlie the Britt and the Kiosk domains to the west and

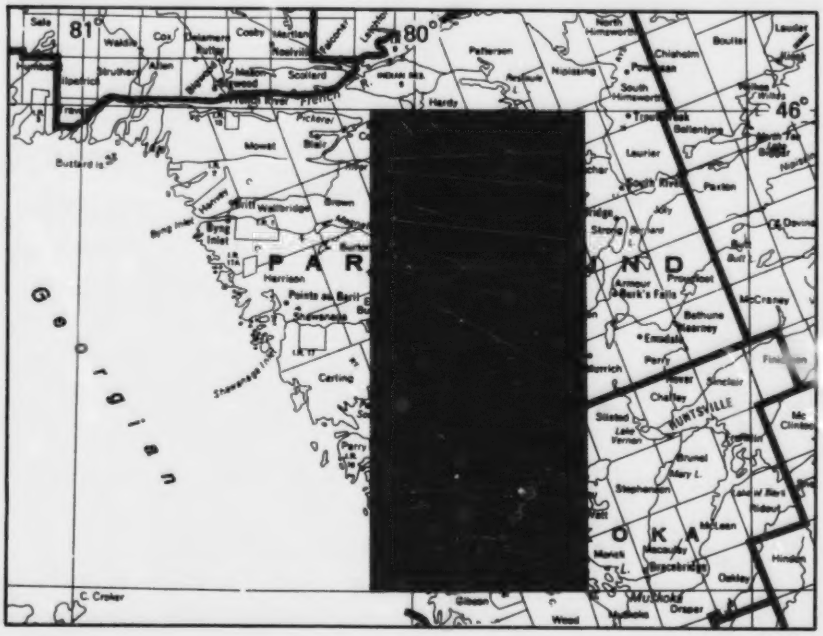

Figure 47.1. *Location map for the remote sensing study in the Parry Sound Domain area, Grenville Province. Scale: 1:1 584 000.*

This project A.2.1 is part of the five year Canada-Ontario 1985 Mineral Development Agreement (COMDA), a subsidiary agreement to the Economic and Regional Development Agreement (ERDA) signed by the governments of Canada and Ontario.

east, respectively, and the Rosseau Subdomain to the southeast (Davidson and Grant 1986). The Parry Sound Domain is in turn overlain by the Moon River and the Seguin subdomains to the southeast. Zones of intensely deformed rocks form the boundaries between the various domains. Ductile deformation occurred at upper and mid-amphibolite facies. Brittle faults associated with the Ottawa-Bonnechere Graben (Kay 1942; Kumarapeli 1976) trend east to northeast with little displacement observed along them (Culshaw *et al.* 1988).

PREVIOUS WORK

Harris *et al.* (in press) investigated the curvilinear features of the Grenville Province of both Quebec and Ontario, at a scale of 1:250 000. They demonstrated that the curvilinear features were clearly visible on Landsat and Seasat images. When analyzed visually, they found that those lineaments could locally be correlated with known geological features such as tectonic domain boundaries, shear zones, and folds.

However, visual interpretation may yield arguable results, and lineament literature abounds in warnings against the subjective nature of lineament maps (Burns and Brown 1978; Parsons and Yearley 1986). This has stimulated research to measure the reliability and reproducibility of such maps (Burns and Brown 1978; Huntington and Raiche 1978; Koopmans 1986; Parsons and Yearley 1986). From these, it is obvious that lineament maps are highly variable, depending on technical factors such as time of scene acquisition, bands used, and resolution, and human factors such as interpretation criteria, experience, and fatigue of the interpreter.

In an attempt to perform a more objective analysis of lineament maps, it is becoming common to reduce the importance given to one given lineament, and instead emphasize lineament families. Density is an increasingly used parameter in map analysis (McGuire and Gallagher 1976; Sawatzky and Raines 1978; Abel-Rahman *et al.* 1978; Pitz and Thiessen 1986). Density is usually evaluated using the cumulative lineament length per given area. In the literature, straight lineaments are favored over curvilinear features, probably due to the interest of the mineral industry combined with the relative simplicity of straight lineaments. The objective study of curvilinear features is scarce in the literature (Peterson 1974).

METHODOLOGY

Cloud free Landsat-5 TM-images acquired on 1986-10-25 were projected and enlarged to a scale of 1:100 000 over a mylar sheet using a Procom-2 projector to cover the Parry Sound Domain (Figure 47.1). Curvilinear features representing unit contact, layering, foliation, and ductile shear zones were traced, while brittle straight features were not included. The curvilinear features are not always concordant and in places cut one another. It is possible that some of them represent glacial features. However, in the light of the observations of McRoberts and Tremblay (1987) and Culshaw *et al.* (1988) who showed that two phases of migmatization and thus two gneissic foliations may coexist in some parts of the Grenville, the non-concordant curvilinear features were traced as they may represent two different phases of ductile deformation.

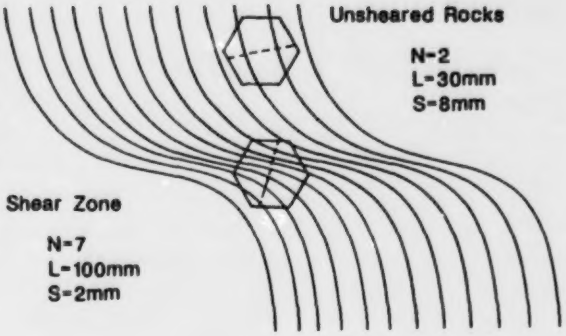

Figure 47.2. *Shear zone geometry redrawn after Ramsay (1980). The hexagon in the unsheared part has a lower lineament density than within the shear zone, as indicated by the parameters N, L, and S. For definition of those parameters, refer to the text.*

Three parameters were used to evaluate the lineament density: 1) cumulative lineament length "L"; 2) number of lineament "N"; 3) average spacing of lineament "S". Those parameters were measured for each hexagonal cell 2 cm in diameter, measured from the corners (Figure 47.2), over an objective rhombic grid with a=1 cm covering the lineament map. A mapping wheel was used to tabulate "L" to the nearest 5 mm. "N" and "S" were measured across a line perpendicular to the trend of the lineaments within the hexagon and going through the centre of the cell.

Since the objective of the study is to determine the position of tectonic domain boundaries, it becomes necessary to find a technique that could help identify shear zones. The examination of Ramsay's diagrams (1980) suggests that the morphology of a shear zone is typified by foliation planes more closely spaced within the shear zone than in the unsheared rocks. Therefore, at a large scale, the lineament density could be expected to be higher in a shear zone. Therefore, as an attempt to enhance lineament density, the three parameters L, N, and S were used to determine a factor D:

$$D= (L)(N)/S$$

Results were than contoured. Lakes were treated as map boundaries and contours were stopped at their margins.

RESULTS

In order to identify domain boundaries, the interpretation of the lineament map was carried on using the same criteria used by Harris *et al.* (in press): truncation relationships and continuous belts of lineaments juxtaposed to zones of contrasting lineament distribution. Using those parameters, it appears that the western boundary of the Parry Sound Domain correlates well with the geological boundaries as determined by Davidson and Grant (1986) and McRoberts and Tremblay (1988). The northern boundary is more vague, while the eastern boundary is not defined by a continuous lineament belt but appears as a gradual boundary between zones of contrasting lineament density. The absence of lineament belt is supported by the recent field investigations of Macfie (this volume), who found that no specific shear zone was defining the eastern boundary of the Parry Sound Domain.

The correlation between the lineament map and the contoured density map is relatively poor. In the density map, areas of high lineament density may locally parallel the trend of the foliation, but are more commonly oriented at an angle apparently unrelated to the structure. Although those areas are representative of high lineament density on the map, they cannot readily be used for structural interpretation.

When compared to the geological data, the density map shows a good level of correlation with the eastern boundary of the Parry Sound Domain. In this zone, very low and high lineament densities are sharply juxtaposed. The northern boundary is more vaguely defined and the western boundary appears intermittently as zones of high lineament density. In the northern and the western boundaries, the orientation of the high density zones parallels the trend of the lineaments. However, the presence of other high density zones apparently randomly distributed throughout the area makes the identification of the domain boundary difficult.

Correlation between the density map and aeromagnetic data (Map 1486G and 1498G at 1:63 360, Geological Survey of Canada 1965) yields more interesting results. Correlation between lineament density and aeromagnetic readings commonly corresponds in location and extent. Locally, high density zones may correspond to high or low aeromagnetic readings. Correlation is coarse and subject to interpretation, but can hardly be fortuitous.

DISCUSSION AND CONCLUSION

As previously determined by Harris *et al.* (in press), the lineament pattern can be used to define tectonic domain boundaries with a fair degree of correlation with known geological data. It can be used as a reconnaissance tool before field investigation.

The density map correlates moderately well with geological data,· but agrees better with the aeromagnetic map. The reason for this is unknown. One can speculate that aeromagnetic signatures depend on rock types, which in turn will display characteristic textures in a Landsat image. One of the factors influencing the textural variation is the lineament distribution. This may explain the correlation but remains to be demonstrated.

The distribution of high density zones in the density map appears greatly affected by the presence of swamps, lakes, rivers, overburden, and cultivated areas. These usually correspond to zones of low lineament density, and offset the pattern attributable to geological factors. One way to compensate for this problem is to interpolate data in the low density zones (Frank Kenny, Ontario Centre for Remote Sensing, Toronto, personal communication, 1988), or to treat swamps, lakes etc. as map borders, and not generate data for these zones. In this map, these zones were found to be too numerous to apply any of the two solutions, as the map would have consisted of 50 percent interpolated data, or 50 percent holes. At this stage, this problem is not solved, and remains central if one aims to use density maps for structural purposes.

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48. Project 86–42. The Precambrian–Paleozoic Unconformity in Southeastern Ontario and Associated Mineralization

G. Di Prisco

Geologist, Precambrian Geology Section, Ontario Geological Survey, Toronto.

INTRODUCTION

The work carried out during this past summer was the final field season of a three-year study of the Precambrian–Paleozoic unconformity in southeastern Ontario. The purpose of the study is to locate and document the unconformity and its related features, and to describe mineralization found at, or in the vicinity, of the unconformity.

Field work in 1988 was carried out in two areas. The northern area lies within the counties of Renfrew and Lanark, close to Renfrew, Arnprior, White Lake, and Calabogie, while the southern area, within the counties of Hastings and Peterborough, extends from Tweed to Havelock (Figures 48.1 and 48.2).

In addition to the research and documentation of Precambrian–Paleozoic contacts and related mineralization, special attention was paid to features of unconformity such as paleosols, paleokarst and supergene enrichment, especially in the metamorphic aureoles of certain plutonic bodies.

GENERAL GEOLOGY

The study areas are underlain by both Precambrian and Paleozoic rocks.

PRECAMBRIAN ROCKS

The Precambrian rocks of this region belong to the Central Metasedimentary Belt (CMB) of the Grenville Province. The Central Metasedimentary Belt is divided into several terranes (Moore 1982), and the areas examined this summer lie mainly in the Elzevir Terrane (Figure 48.2).

The Elzevir Terrane is composed of rocks of middle Proterozoic and includes volcanic, volcaniclastic, and intercalated carbonate and siliciclas-

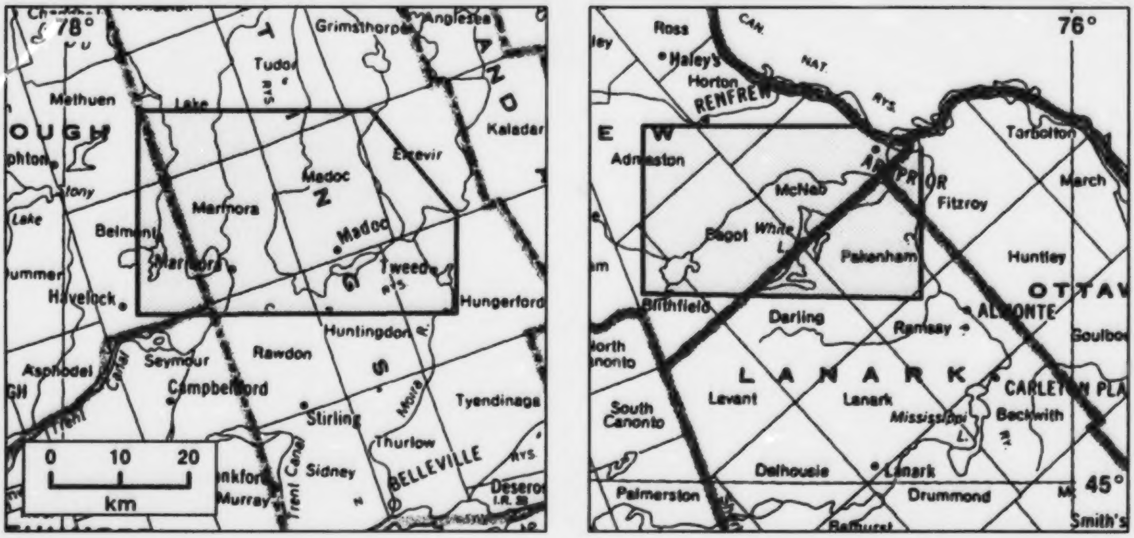
78°
Grimsthorpe
Anglesea
Tudor
Methuen
Kaladar
Elzevir
Madoc
Marmora
Belmont
Havelock
Tweed
Hungerford
Huntingdon
Rawdon
Seymour
Asphodel
Campbellford
Stirling
Tyendinaga
Thurlow
Sidney
Belleville
Trent Canal
Moira
Murray
Deseronto
0 10 20
km
76°
Ross
Haley's
Horton
Renfrew
Admaston
Arnprior
Tarbolton
March
McNab
Fitzroy
White L.
Pakenham
Huntley
Blithfield
Darling
Ramsay
Almonte
Ottawa
Goulbourn
Lanark
Levant
Carleton Place
South Canonto
Mississippi L.
Beckwith
Dalhousie
Lanark
Palmerston
Drummond
45°
Smith's

Figure 48.1. *Location map.*

This project A.1.1 is part of the five year Canada-Ontario 1985 Mineral Development Agreement (COMDA), a subsidiary agreement to the Economic and Regional Development Agreement (ERDA) signed by the governments of Canada and Ontario.

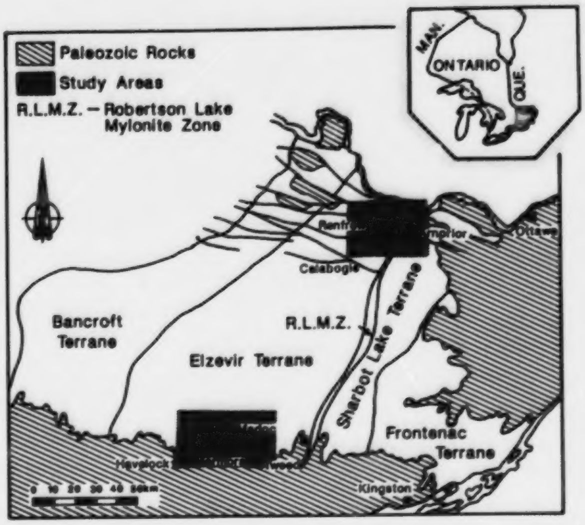
▨ Paleozoic Rocks
■ Study Areas
R.L.M.Z. – Robertson Lake Mylonite Zone
MAN.
ONTARIO
QUE.
Renfrew
Arnprior
Ottawa
Calabogie
Bancroft Terrane
R.L.M.Z.
Elzevir Terrane
Sharbot Lake Terrane
Frontenac Terrane
Havelock
Kingston
0 10 20 30 40 50km

Figure 48.2. *Structural subdivisions of the Central Metasedimentary Belt, Grenville Province, Ontario (from Moore 1982; Easton, in press).*

tic sedimentary rocks (Grenville Supergroup), all intruded by several plutonic suites. The Flinton Group, which is interpreted to overlie the Grenville Supergroup (Moore and Thompson 1972), consists of carbonate and clastic sedimentary rocks.

The Elzevir and adjacent terrane were subjected to two phases of metamorphism during the middle Proterozoic (Easton 1986). Most of the southern area preserves greenschist facies rocks, while in the northern area amphibolite facies rocks are common.

PALEOZOIC ROCKS

The Paleozoic rocks overlie the Precambrian basement south and northeast of the Central Metasedimentary Belt. According to Liberty (1963), the Paleozoic succession in the study area begins with the clastic sediments of the Shadow Lake Formation of lower Ordovician age, followed by the carbonate sediments of the Gull River and Bobcaygeon formations. The Verulam and Lindsay formations, outcropping farther south, were not observed in the study areas.

RENFREW–ARNPRIOR–CALABOGIE AREA

This study area is located in the northern part of the Elzevir Terrane at the border of the Sharbot Lake Terrane. The Robertson Lake Mylonite Zone separates the two terranes (Figures 48.2 and 48.3). Work in this area had three goals:

1. to find and examine exposures of the unconformity
2. to study the relationship between mineralized veins and the unconformity

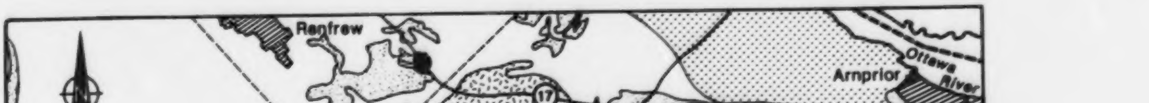
Renfrew
Arnprior
Ottawa River
ADMASTON
HORTON
17
508
River
McNAB
Norway Lake
Madawaska
BAGOT
Dempsey Lake
Calabogie Lake
White Lake
511
BLITHFIELD
DARLING
1
2
3
4
5
Paleozoic rocks
PRECAMBRIAN
Biotite-diorite plutonic rocks
Metasediments
Undifferentiated Precambrian rocks
⚒ Iron
1 Dempsey Lake Mine
2 Con.XI, Lot 23, Hematite Mine
★ Gold anomaly
3 Culhane Mine
4 Lerond Mine
5 Williams Mine
● Precambrian–Paleozoic contact
0 1 2 3 4 5km

Figure 48.3. *Synoptic geological map of the Renfrew–Arnprior–White Lake–Calabogie area (from Carter et al. 1980; Lumbers 1982).*

TABLE 48.1. ASSAY RESULTS FROM SELECTED SAMPLES FROM THE 1988 STUDY AREAS (ANALYSES BY THE GEOSCIENCE LABORATORIES, ONTARIO GEOLOGICAL SURVEY, TORONTO).

Sample Number	Location	Au/ppb
Renfrew-Arnprior-Calabogie Area (iron skarn deposits, supergene zone)		
G.D.P 88 -09	Culhane deposit, Bagot Township 366500mE 5021930mN (31 F/7)	13
G.D.P 88 -10	Lerond deposit, Bagot Township 363410mE 5020635mN (31 F/7)	21
G.D.P 88 -11	Williams deposit, Bagot Township 361990mE 5018940mN (31 F/7)	21
Tweed-Madoc-Marmora-Havelock Area (iron skarn deposits, supergene zone)		
G.D.P 88 -17	Knob Mine, West, Madoc Township 295250mE 4938850mN (31 C/12)	13
G.D.P 88 -18	Knob Mine, West, Madoc Township 295250mE 4938850mN (31 C/12)	20
G.D.P 88 -20	Hobson Mine, East, Madoc Township 295880mE 4939182mN (31 C/12)	32
G.D.P 88 -21	Hobson Mine, East, Madoc Township 295880mE 4939182mN (31 C/12)	40
G.D.P 88 -34	Madoc West, Madoc Township 301760mE 4930420mN (31 C/11)	17
G.D.P 88 -36	Highway 7, West of Madoc, Madoc Township 298950mE 4930500mN (31 C/5)	20
G.D.P 88 -37	Dominion Mine, Madoc Township 297920mE 4929450mN (31 C/5)	30
G.D.P 88 -38	Deloro North, Marmora Township 291415mE 4934195mN (31 C/12)	16

3. to examine the features of the unconformity in the metasomatic aureoles of various plutonic bodies

Outcrops exposing Precambrian–Paleozoic contacts are not common in this area, and with the exception of a few localities (Figure 48.3), contacts are obscured by overburden.

Several historic mines of carbonate, sulphide, sulphate, and oxide metallic mineralization were visited. In most, mineralization is hosted in fractures that cut both the Precambrian and Paleozoic rocks, and which is most likely related to a late tectonic event.

However, a clear genetic interpretation is not apparent for the carbonate–sulphate ore deposit at Dempsey Lake, Bagot Township, or the hematite mine on lot 23, concession XI, Darling Township (Figure 48.3). Both occurrences are situated in Precambrian carbonate metasediments and show a brecciated mineralized habit which is interpreted to represent mineralization of karst collapse structures that developed along the Precambrian surface.

Finally, selected iron skarn deposits were visited to search for potential secondary supergene reconcentration (Figure 48.3). Assays of samples from these deposits indicate a slight gold enrichment in the weathered zones of the occurrences (Table 48.1).

TWEED–MADOC–MARMORA–HAVELOCK AREA

This area lies in the southern part of the Elzevir Terrane and is overlapped to the south by Paleozoic rocks. Several outliers of Paleozoic rocks outcrop in front of the main Precambrian–Paleozoic boundary (Figure 48.4).

A more detailed study of previously identified unconformities (Springer 1985; Di Prisco 1986, 1987) has been carried out in this area. Precambrian paleosols and paleokarsts with associated mineralization underneath the Paleozoic rocks, were examined in finer detail (Figure 48.4).

Previous work (Di Prisco 1986, 1987) shows that the most interesting and promising unconformity–related features are located in the metasomatic aureoles surrounding plutonic bodies belonging to the biotite–diorite suite of Lumbers (1967). Therefore, research focused on this environment, particularly around the Deloro Batholith in Madoc and Marmora townships where many skarn ore deposits outcrop. Supergene reconcentrations at the Precambrian surface, above iron and sulphide deposits, were examined and sampled. Preliminary assays indicate a slight gold enrichment in the weathered zones of certain of these skarn ore deposits (Table 48.1).

ECONOMIC IMPLICATIONS OF THE PRECAMBRIAN–PALEOZOIC UNCONFORMITY

Exposed for a long period of time in a subaerial environment and under semi–arid climatic conditions, the Precambrian land surface was subjected to weathering processes. Dissolution, transportation, and redeposition of minerals and fragments of the weathered Precambrian basement occurred. As a result, paleosols, paleokarsts, supergene alteration, and supergene reconcentration of existing mineralization formed. Metal reconcentration in some places was sufficient to form secondary ore deposits at the Precambrian land surface, some of which were mined (Wallbridge Iron Mine, Coe Mine). Nevertheless, the secondary reconcentration is usually not wide–scale enough to allow mining. However, these widespread discrete supergene alterations can indicate geochemical anomalies associated with ore deposits in the immediately underlying Precambrian rocks. Thus, the recognition of weathering features related to the unconformity can be used as an exploration tool for the survey of precious and base metals in the Precambrian basement.

Exploration of buried Precambrian ore deposits can benefit from the observation of earliest Paleozoic sediments. As noted previously (Di Prisco 1986, 1987), mechanically reconcentrated ore fragments are only found in the basal Paleozoic clastic units in close proximity to Precambrian ore deposits. Therefore, the presence of ore clasts in the basal Paleozoic units would suggest the presence of a nearby Precambrian ore deposit.

In the Central Metasedimentary Belt, gold has been found in weathered horizons of historic Precambrian skarn deposits, i.e. Richardson Gold Mine (Vernor 1870), Cordova Mine (Blue 1894), Sofia Mine (Slaght 1898). More recently, gold enrichment has been observed at the Precambrian land surface, in the same geological context by Di Prisco and Springer (1988). Therefore, study of supergene

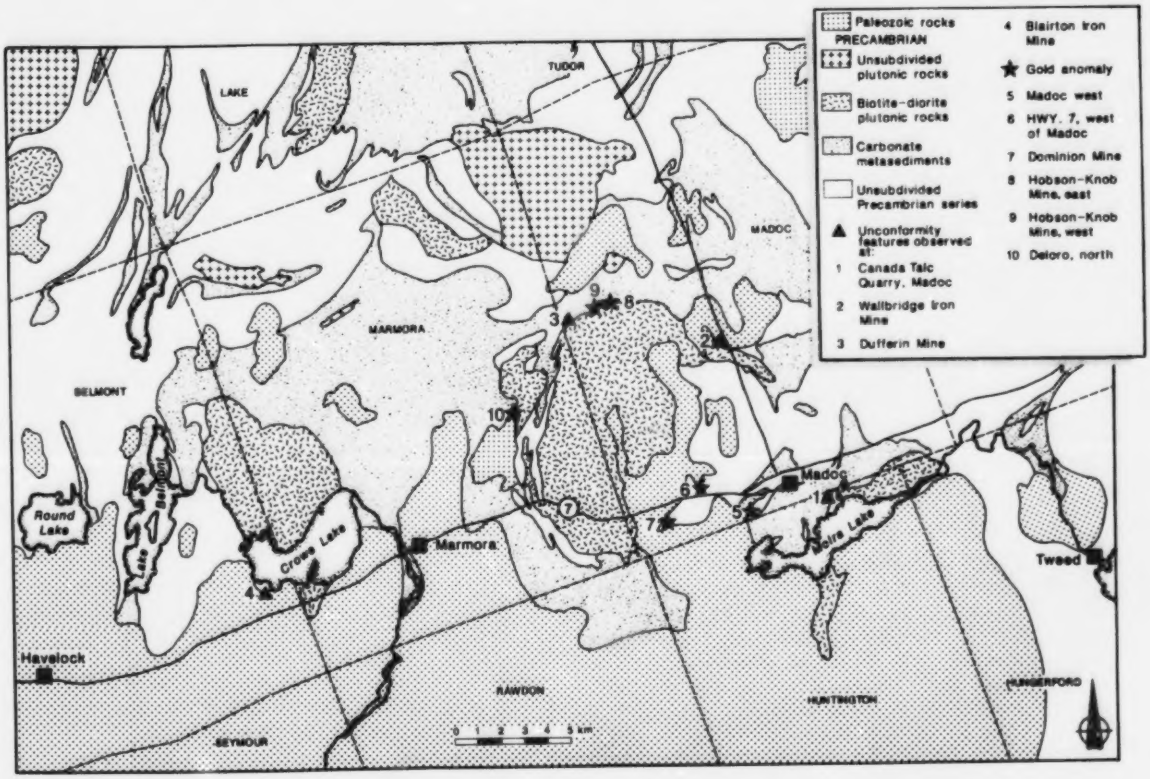
Paleozoic rocks
PRECAMBRIAN
Unsubdivided plutonic rocks
Biotite–diorite plutonic rocks
Carbonate metasediments
Unsubdivided Precambrian series
▲ Unconformity features observed at:
1 Canada Talc Quarry, Madoc
2 Wallbridge Iron Mine
3 Dufferin Mine
4 Blairton Iron Mine
★ Gold anomaly
5 Madoc west
6 HWY. 7, west of Madoc
7 Dominion Mine
8 Hobson–Knob Mine, east
9 Hobson–Knob Mine, west
10 Deloro, north
LAKE
TUDOR
MADOC
MARMORA
BELMONT
Round Lake
Lake Belmont
Crowe Lake
Marmora
Madoc
Moira Lake
Tweed
Havelock
RAWDON
HUNTINGTON
HUNGERFORD
SEYMOUR
0 1 2 3 4 5 km
1
2
3
4
5
6
7
8
9
10

Figure 48.4. *Simplified geological map of the Tweed–Madoc–Marmora–Havelock area (from Kingston et al. 1985).*

reconcentration so far has been oriented toward the investigation of metasomatic aureoles surrounding plutonic bodies in which skarn ore deposits are widespread and abundant.

Ore deposits other than those related to metasomatic processes would also have been affected by Precambrian weathering. Hence, this weathering may prove to be a useful exploration tool for ore deposits as varied as the volcanogenic massive–sulphide, polymetallic stratabound, and fault–related deposits common in the Grenville Province in southeastern Ontario. Special attention should also be paid to exploration of gold along weathered horizons of the Robertson Lake Mylonite Zone and to gold associated with weathering in volcanogenic massive sulphide of Montauban or New Calumet type ore deposits (*see* Easton, this volume).

SUMMARY

During the late Proterozoic, the Precambrian land surface remained exposed in a subaerial environment for several hundred million years. This surface was subjected to weathering processes which lead to metal reconcentration at the Precambrian surface. Therefore, the recognition of features related to the Precambrian–Paleozoic unconformity can help in the exploration for precious and base metals.

Study of these weathering features in the metasomatic aureoles of Grenville plutonic rocks has provided information about metal reconcentration above skarn deposits and has shown the utility of this approach in exploration. It is felt that this method may prove to be a useful tool in exploration for various mineral deposits hosted in Precambrian rocks in southeastern Ontario.

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49. Project Number 88–35. Hematitized Fault Zones in the North Bay Area

J.S. Springer

Geologist, Precambrian Geology Section, Ontario Geological Survey, Toronto.

INTRODUCTION

Paleozoic, post–Ordovician faulting and fracturing of both the Grenvillian and Paleozoic rocks in southeastern Ontario have been the focus of investigations since the early 1980s (Williams *et al.* 1984). Lead–zinc, minor silver (Carter 1984), and barium–strontium–fluorine mineralization (Williams 1982) are locally associated with the fracturing and warrant exploration.

The study of post–Ordovician fractures and faults could indirectly lead to the discovery of mineralization related to the Precambrian–Paleozoic unconformity investigated by Springer (1985), Churcher (1986), and Di Prisco (1986, 1987). It is known from the work of these researchers that weathering of Precambrian rocks can lead to ore enrichment, for example, the concentration of high–grade hematite ore, which locally may be exploitable as quality pigment. It now appears that weathering at the unconformity was especially strong at Precambrian fault and fracture zones, several of which were active during the Paleozoic. Therefore the study of fracture and fault systems in southeastern and central Ontario contributes to the understanding of the geological history and has some significance to concentration of mineralization.

The author selected two known hematite occurrences, which are associated with faulting, for detailed investigations. These two occurrences are among many which are scattered in central Ontario close to the Paleozoic–Precambrian unconformity. Locality 1 is south of Lake Nipissing in Nipissing Township; locality 2 is on Highway 11, 3.9 km south of the town of Powassan in South Himsworth Township.

LOCALITY 1

South of Lake Nipissing (Figure 49.1), a small outlier of Paleozoic rocks bounded to the south by an east–trending fault has been described by Satterly (1942) and Lumbers (1971). Lumbers calls this east–trending fault the Nipissing Fault and infers that it marks the southern margin of the Ottawa–Bonnechere Graben. The limestones which make up the bulk of the section are richly fossiliferous and thus can be placed in the upper Middle Ordovician Rockland stage of the Champlanian Series (Williams and Telford 1986).

Hematite occurs along the Nipissing Fault, and Lumbers (1971, p.76) described the occurrence as follows:

> "In lot 218, Concession A, Nipissing Township, hematite-enriched, silicified, brecciated granitic rocks of the Powassan batholith, exposed in the Nipissing Fault at the base of a talus slope on the south side of the Paleozoic outlier about 1.7 miles west of Nipissing, have been explored for iron. The main showing is about 800 feet south of the road

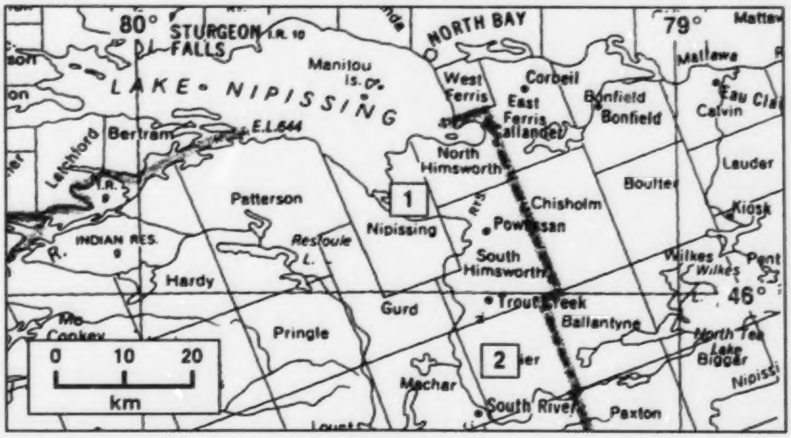
80°
STURGEON FALLS
I.R. 10
NORTH BAY
79°
Manitou Is.
LAKE NIPISSING
West Ferris
Corbeil
East Ferris
Callander
Bonfield
Bonfield
Calvin
Mattawa
Bertram
E.L.644
Latchford
I.R. 8
North Himsworth
Lauder
Boulter
Patterson
1
Chisholm
Kiosk
Powassan
Nipissing
INDIAN RES. 9
R.
Restoule L.
South Himsworth
Wilkes
Wilkes
Hardy
46°
Trout Creek
Gurd
Ballantyne
Pringle
North Tea Lake
2
Biggar
0
10
20
km
Machar
South River
Paxton

Figure 49.1. *Location map for the North Bay study area. Numbers 1 and 2 refer to localities discussed in this report.*

leading west from Nipissing and was explored in 1941 by a 300-foot diamond drill hole put down by W. Holder, and in 1951 and 1952, by gravimetric and geological surveys completed for J.H. Dumouchel (assessment work files, Resident Geologist, Ontario Department of Mines and Northern Affairs, Toronto). This work failed to disclose economic concentrations of iron".

When Satterly (1942, p.47) visited the occurrence exposure was better:

> "The hematite deposit is at the base of a talus slope 12 chains from the road. Between the deposit and the road, Paleozoic dolomite is exposed from 1 to 6 chains south of the road. The talus cliff is 50 feet high, and the talus consists of fragments of granite gneiss stained with a red film of hematite. Examination of the cliff face shows a granite gneiss breccia with a cement of reddish-brown hematite. This cliff peters out westward. As no outcrops east or west of the exposures mentioned were found, it is not known how big an area is underlain by the dolomite.
>
> At the time of the writer's visit on July 26, 1941, no new work had been done on the deposit, and nothing could be seen in a partially caved-in timbered pit at the base of the talus. The only hematite seen was on the dump. This material is a hard, fine-grained, grey and brown hematite containing disseminated glassy quartz."

Lumbers (1971, p.76) further reports that:

> "A grab sample collected by Satterly (1942, p.41) from the dump near the old pit gave upon assay 55.65 percent Fe, 18.73 percent SiO_2 and 0.10 percent S. The diamond drill hole intersected 1- and 3-foot sections that gave upon assay 41.26 and 34.62 percent iron respectively."

In recent years a quarry has been opened along the fault by Mr. Stanley Moore, Powassan, to provide fill and road metal from the Precambrian bedrock. Quarrying has uncovered the fault, as well as the unconformity of Paleozoic on the Grenvillian rocks (Figure 49.2). Several generations of fracturing, associated with different fault-fill materials can be seen. The east-trending Nipissing Fault is obviously a younger structure which cuts older mylonite zones. The following observations were made by the author:

1. The Precambrian gneisses have been crushed and form a red, flinty mylonite along northwest-oriented fracture planes. This deformation is pre-Middle Ordovician in age, as the nearby Ordovician rocks are not affected by it.
2. Both the gneisses and the mylonite zones have been fragmented and weathered to rounded cobbles.
3. The cobbles, in part, have been incorporated into a yellow-green, matrix-supported conglomerate that forms the base of the Paleozoic sequence. The fine fraction of this conglomerate contains very well rounded quartz grains.
4. The later, east-trending Nipissing Fault is marked by a green, chloritic fault gouge. The fault has affected both the Precambrian and Paleozoic rocks. The Paleozoic limestone beds are cut by faults that parallel the main fault. The Paleozoic limestones step down northwards on

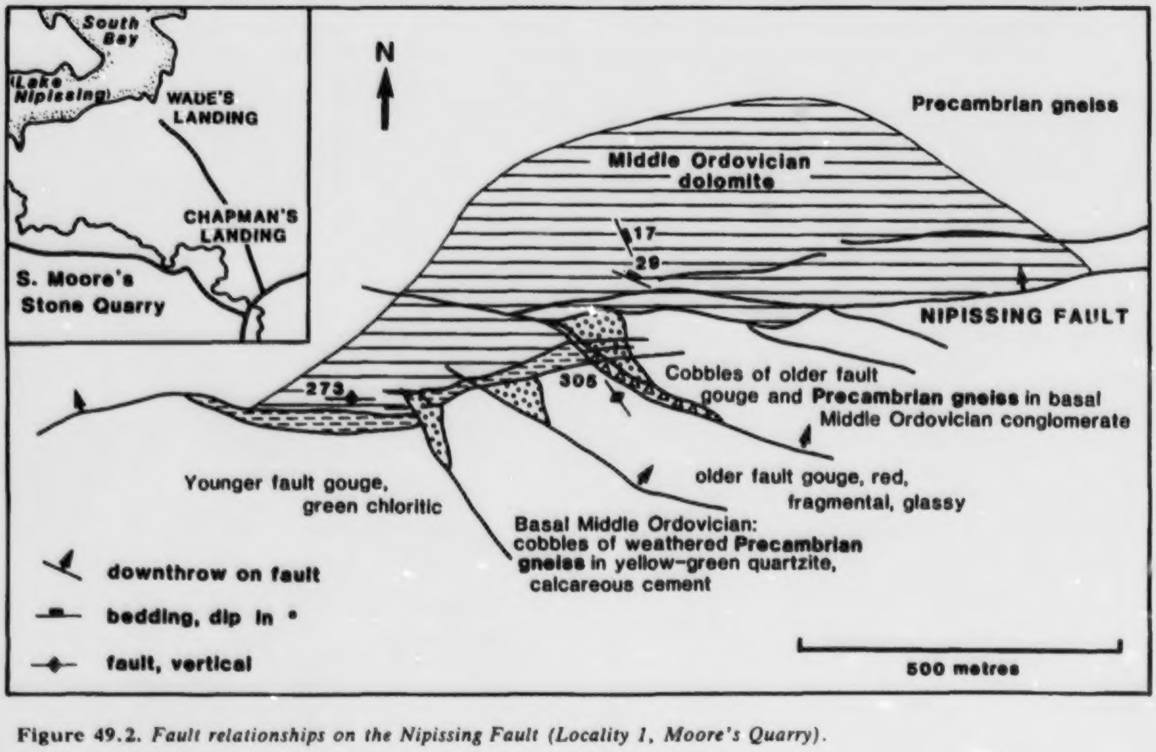
South Bay
(Lake Nipissing)
WADE'S LANDING
CHAPMAN'S LANDING
S. Moore's Stone Quarry
N
Precambrian gneiss
Middle Ordovician dolomite
17
29
NIPISSING FAULT
273
305
Cobbles of older fault gouge and Precambrian gneiss in basal Middle Ordovician conglomerate
Younger fault gouge, green chloritic
older fault gouge, red, fragmental, glassy
Basal Middle Ordovician: cobbles of weathered Precambrian gneiss in yellow-green quartzite, calcareous cement
downthrow on fault
bedding, dip in °
fault, vertical
500 metres

Figure 49.2. *Fault relationships on the Nipissing Fault (Locality 1, Moore's Quarry).*

these later fault lines. The dip of the beds steepens from almost horizontal to 30° close to the fault and strikes become subparallel to the fault. The fragments in the fault gouge are loosely cemented by a vuggy framework of encrusting calcite and pyrite.

5. Present activity at the fault zone includes a spring that arises along it and is tapped by local cottages. Hydraulic water flow on the fault line is depositing tufa, and redistributing iron hydroxides so that fragments of the gneisses and the basal conglomerate are becoming recemented and coated with limonite and hematite. This appears to be the hematite ore reported by Satterly (*see* above).

LOCALITY 2

Previous work by Lumbers (1971; p.66) identified this locality on Highway 11, 3.9 km south of the town of Powasson in South Himsworth Township where a fault breccia in monzonite is cemented with a hematite-rich matrix.

For the greater North Bay area, Lumbers (1971) has clearly pointed to the long, complex history of the fracture systems that strike west–northwest. He deduces that this system has controlled the emplacement of both diabase and lamprophyre dikes; that their age spans the Late Proterozoic to Early Paleozoic; and that the Cambrian alkalic intrusions (565 Ma old, Gittins *et al.* 1967) are intimately connected to the formation of the Ottawa–Bonnechere Graben.

At locality 2 (Figure 49.1, Figure 49.3) the following observations were made:

1. North–northwest-trending fracture planes (about 330° to 340°) are filled with dark-red flinty mylonite and show a sinistral sense of motion.
2. Fracture and fault zones control the intrusion of lamprophyre dikes, whose margins are chilled against the Precambrian monzonite gneiss. The dikes, striking about 030°, thin within the mylonite zones but are not disrupted.
3. Later hematized fracture planes striking about 250° to 260° displace the lamprophyre dikes with a dextral sense of motion.

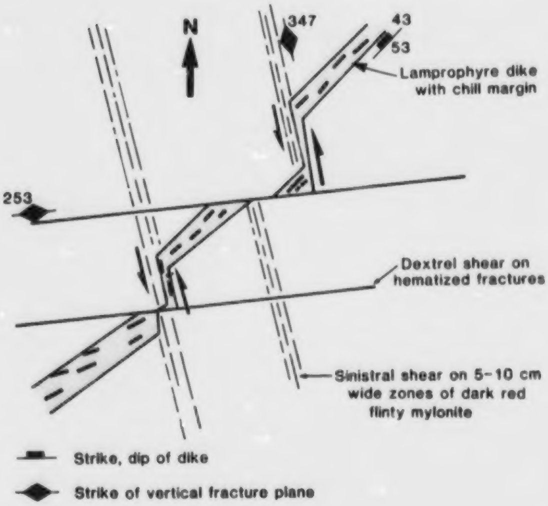
N
347
43
53
Lamprophyre dike with chill margin
253
Dextrel shear on hematized fractures
Sinistral shear on 5–10 cm wide zones of dark red flinty mylonite
Strike, dip of dike
Strike of vertical fracture plane

Figure 49.3. *Structural relationships, Highway 11, 3.5 km south of Powassan (Locality 2).*

Lumbers (1971) has argued a Cambrian age for the lamprophyre dikes, regarding them as accompanying the 565 Ma old, alkalic intrusive event in the Lake Nipissing area. Present observations confirm that a north–northwest–oriented fracture event, marked by flinty mylonite, took place before the deposition of the Paleozoic rocks. The lamprophyre dikes, controlled by the north–northwest–directions, must be coeval with or later than this fracture event. Later hematitized fault planes, striking eastward, postdate both the mylonite and the lamprophyres.

At this locality, there is no evidence that hematitization is related to the Paleozoic unconformity. The hematitized fault zones are probably post–Cambrian, but cannot be dated precisely.

CONCLUSIONS

Several hematite occurrences in southeastern and central Ontario are related to strong alteration in fault and breccia zones. Both Precambrian and Paleozoic faulting can be responsible for the alteration and, in places, Precambrian weathering appears to be especially strong at Precambrian fault zones (*see* Easton, this volume; Di Prisco, this volume). Thus, these fault and fracture zones have potential for high quality pigment and possibly for gold.

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50. Stratigraphy and Sedimentation of Marbles and Associated Metasedimentary Rocks of the Grenville Supergroup in Southeastern Ontario

Hans D. Meyn

Regional Specialist, Bancroft, Ontario.

INTRODUCTION

Since the middle of the 19th century, the carbonate rocks of the Grenville Province in Ontario have contributed to the mineral production of Ontario. Iron was one of the earliest metals produced from marble–hosted deposits of the Grenville. In addition, graphite, zinc, mica, marble for building stone, and marble for lime production has come from Grenville marbles (Hewitt and Vos 1972; Storey and Vos 1981a, 1981b; Carter 1984; Malzak *et al.* 1985)

At present, marbles are used for filler, chips for concrete facing and similar uses, for golf sand, chicken grit, mortar, and white bricks. Talc is produced from dolomitic marble at Madoc, and at Haley Station, dolomitic marble is used for the production of magnesium.

Future additional production of marble, and marble–hosted talc, tremolite, and wollastonite as mineral fillers, as well as additional graphite, and zinc production is likely.

Field work in 1987 began in the Belmont–Madoc area, an area underlain by low grade metamorphic rocks, to study the stratigraphy and petrography of the marbles and the mineralization environments associated with them. At that time, the calcitic and dolomitic marbles of Belmont Lake and the stromatolitic dolomite on Big Island of Belmont Lake, Belmont Township, seemed to be at or near the base of the thick marble sequence of the Belmont–Marmora area. In 1988, field work concentrated on the Belmont Lake area located in the Central Metasedimentary Belt of the Grenville Province (Figure 50.1).

GENERAL GEOLOGY

In general, little detailed work has been done on sedimentary rocks, or the marbles in particular, in the Central Metasedimentary Belt of the Grenville

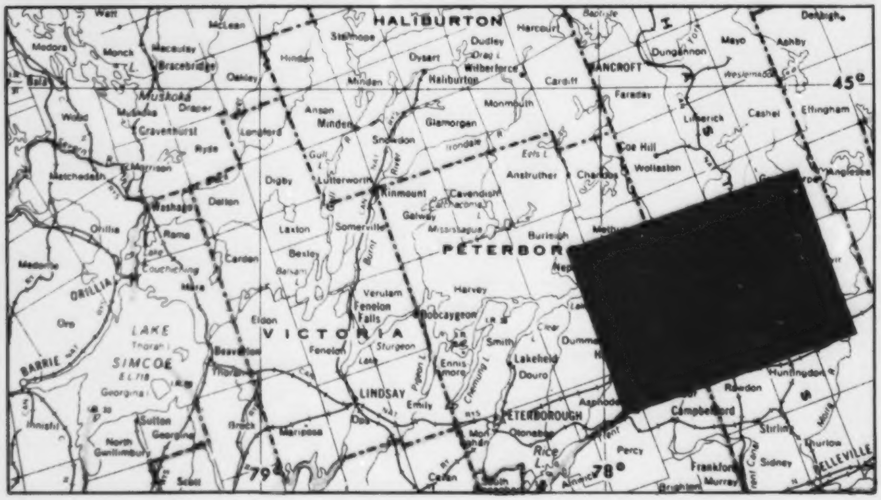

Figure 50.1. *Location map of the study area in Southeastern Ontario. Scale: 1:1 584 000 or 1 inch to 25 miles.*

CANADA ONTARIO

This project A.1.4 is part of the five year Canada-Ontario 1985 Mineral Development Agreement (COMDA), a subsidiary agreement to the Economic and Regional Development Agreement (ERDA) signed by the governments of Canada and Ontario.

Province in Ontario. Among the earliest workers were Adams and Barlow (1910) who recognized amphibolite layers in marble as metasediments, and Miller and Knight (1914) who synthesized the Precambrian geology of Southeastern Ontario. A more general overview of the local and regional metasedimentary geology is given by Lumbers (1964) and Hewitt (1968). Recent detailed mapping by Bartlett and Moore (1985) and several university theses associated with that project (Murray 1982; Bartlett 1983; Pilon 1981; deKemp 1984) produced 1:15 840 scale maps of Belmont and Marmora townships with an emphasis on the volcanology of the area. At about the same time, field work on a similar project to this author's commenced by Bourque (Bourque 1981, 1982; Bourque *et al.* 1982) and some of the results of that study are contained in Bartlett and deKemp (1987).

BELMONT LAKE FORMATION

Bartlett and co–workers created a separate map unit for the predominantly epiclastic rocks present in southern Belmont Lake (Bartlett *et al.* 1982), which was subsequently named the Belmont Lake Formation.

The Belmont Lake Formation is first defined in Bartlett (1983, p.52): "Named for its areal restriction to the east shore and some islands of Belmont Lake, this formation comprises polymictic granule to cobble (rarely boulder) conglomerate with subordinate sandstone, mudstone and dolomitic marble."

The relationship of this formation to the underlying, overlying, and laterally equivalent rocks is not clearly defined. Bartlett (1983) considered the Belmont Lake Formation to be a lateral equivalent of the Marmora Formation (Bartlett 1983, p.48), which is exposed in northern Belmont Lake and northeast of Belmont Lake. A detailed description of the Belmont Lake Formation is given in Bartlett and Moore (1985), and the reader is referred to this publication for further information. Some features described by Bartlett and Moore (1985) do not apply to all parts of the formation equally.

A pervasive schistosity is developed in all of the rocks of the Belmont Lake area. In much of the Belmont Lake Formation, the strike of the schistosity is parallel to the strike of the sedimentary units and in some instances, the dips are parallel as well, but this is not typical. The schistosity has affected the carbonate units to varying degrees. Some boudinaging of calc–silicate layers and aligning of calc–silicate fragments into layers parallel to schistosity/bedding is common. This feature is best developed near the base of the carbonate sequence where shearing along the contact between the volcanics and the marble may have taken place.

Sedimentary structures such as bedding, including very finely laminated mudstones and dolostones, cross–bedding, and graded bedding are well preserved. Strike direction is generally just east of north. Stratigraphic tops are consistently eastward (up). Bedding is locally vertical to overturned but dips are generally between 30 and 70 degrees east. Indication of paleocurrent direction from cross–bedding is typically eastward.

This summer's field work suggests that the Belmont Lake Formation is composed of a series of fining upward cycles.

A typical fining upward cycle on Belmont Lake starts with conglomerate, followed by cross–bedded sandstone and pebbly sandstone. The sandstone in turn is overlain by ever finer sandstone, grading upward into siltstone and culminating with laminated mudstones. Where conditions were suitable, the clastic sequence is topped by stromatolitic dolomite.

Few complete fining upward cycles have been observed in any single section because of lack of continuous outcrop. Further, each cycle is not always complete in every instance, nor were conditions favourable for deposition of the stromatolitic dolomite at the top of each cycle or along the whole strike length of a cycle.

There occurs on Belmont Lake clastic rocks other than those included in the fining upward cycles. Bartlett and Moore (1985) seem to have included some, but not all, of these rocks in the Belmont Lake Formation. This author hopes to determine the relationship of these rocks to the Belmont Lake Formation as this study progresses.

DISCUSSION

This summer it was recognized that the sequence of clastic rocks centred on Big Island, Belmont Lake, Belmont Township, essentially the same suite of rocks included in Bartlett's (1983) definition of the Belmont Lake Formation, consists of fining upward cycles.

The depositional environment of this clastic sequence is not yet resolved. Bartlett and Moore (1985, p.107) state: "Detailed facies analysis of the predominantly sedimentary Vansickle, Marmora and Belmont Lake formations is not attempted in this report." They go on to say (Bartlett and Moore, 1985, p.109): "The authors' data are presently insufficient to determine the exact nature of sedimentary processes responsible for the deposition of the Belmont Lake Formation. Fluvial processes were important, as evidenced by cross–bedding and scour channels, however, lahars may have contributed significantly, as may have alluvial processes. Whatever the mechanism, the spatial distribution of the Belmont Lake Formation relative to the Cordova Lake Formation suggests that the material was primarily transported down the east flank of the source volcano."

The author of the present study believes that a general model for the environment encountered at

Belmont Lake might be a volcanic island or chain of islands surrounded by a relatively narrow, shallow water carbonate shelf on which carbonate deposition takes place whenever clastic or volcanic/pyroclastic events do not predominate. Such an environment would allow all of the observed volcanic and sedimentary facies to co–exist in close proximity.

Further study will increase the understanding of the paleoenvironment of the carbonate and clastic metasediments in the Central Metasedimentary Belt of the Grenville Province in Ontario and the mineralization environments associated with these rocks.

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51. Pegmatites of the Bancroft Area, Southeastern Ontario

B.E. Goad

Geologist, Ministry of Northern Development and Mines, Bancroft.

INTRODUCTION

Initially, the pegmatites in Monteagle Township just north of Bancroft were studied. In 1988, following the somewhat discouraging results of the 1987 field and laboratory investigations, the work area was expanded to assess the economic potential of other pegmatite areas in the Grenville Province. Pegmatites examined in 1988 include those occurring in the Madawaska area, the Perth/Verona area, Mattawa area, and the Parry Sound/Huntsville areas (Figure 51.1).

MINERAL EXPLORATION

Granitic pegmatites are very common in the Grenville Province. In the past, these pegmatites were exploited, or at least explored, as a source of feldspar, quartz, mica, uranium, thorium, molybdenum, beryllium, and rare earth elements (REE). Past exploration for, and limited production from, pegmatites peaked during the following periods:

1. between 1917 and 1927, when many pegmatites were explored for feldspar and/or mica
2. between 1940 and 1947, when other pegmatite occurrences were examined as sources of mica and/or beryllium
3. during the 1950s, when pegmatites were examined as a source of uranium

The only active commercial pegmatite operations in the study area are at the Rose Quartz Pit and the Beryl Pit in Lyndoch Township (operated by Wal-Gem Lapidary), and at the Blue Star pegmatite in

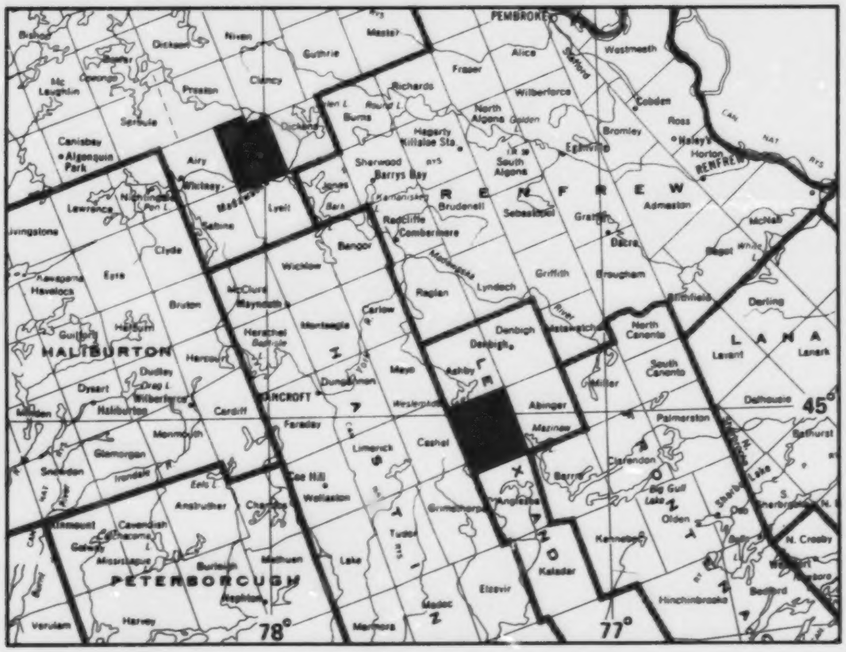
PEMBROKE
Westmeath
Alice
Fraser
Guthrie
Niven
Dickson
Preston
Clancy
Richards
Wilberforce
North Algona
Cobden
Ross
Bromley
Horton
RENFREW
R E N F R E W
Admaston
Brudenell
Sebastopol
Grattan
Eganville
South Algona
Barrys Bay
Sherwood
Airy
Lawrence
Nightingale
Livingstone
Clyde
Sabine
Lyell
Jones
Bangor
Wicklow
Radcliffe
Combermere
Raglan
Lyndoch
Griffith
Brougham
Brudenell
Eyre
Bruton
Harburn
HALIBURTON
Havelock
Guilford
Dudley
Dysart
Harcourt
Haliburton
Cardiff
McClure
Herschel
Monteagle
Carlow
Mayo
BANCROFT
Dungannon
Faraday
Limerick
Cashel
Ashby
Denbigh
Abinger
Matawatchan
North Canonto
South Canonto
Palmerston
Clarendon
Barrie
Anglesea
Kaladar
Elzevir
Kennebec
Hinchinbrooke
Bedford
Olden
Lavant
Lanark
Darling
Dalhousie
Bathurst
N. Crosby
Glamorgan
Monmouth
Snowdon
Coe Hill
Wollaston
Chandos
Anstruther
Cavendish
Galway
Burleigh
Methuen
Lake
Tudor
Grimsthorpe
Madoc
Marmora
PETERBOROUGH
Harvey
Verulam
Canisbay
Algonquin Park
Mc Laughlin
Bishop
45°
78°
77°

Figure 51.1. *Location map for the Bancroft area, Southern Ontario. Scale 1:1 584 000 or 1 inch to 25 miles.*

This project A.1.6 is part of the five year Canada-Ontario 1985 Mineral Development Agreement (COMDA), a subsidiary agreement to the Economic and Regional Development Agreement (ERDA) signed by the governments of Canada and Ontario.

Chapman Township. These are all operated solely for collection of mineral specimens. In 1976 and 1977, the Comet Quartz pegmatite in Murchison Township and the International Quartz pegmatite in McClintock Township produced quartz but operations are inactive at present.

PRESENT STUDY

GENERAL BACKGROUND

The present study was initiated in 1987 to study the pegmatites occurring north of Bancroft in the Grenville Province of Southern Ontario. This study was designed to geochemically classify the pegmatites based on their trace element content and if possible, to relate the pegmatites to parental granitic intrusions. The final goal of the investigations is to provide the mineral industry with a practical tool for pegmatite exploration. Previous studies by Storey and Vos (1981), Masson and Gordon (1981), and Hewitt (1967) classified the pegmatites into groups solely on a descriptive or geographic basis.

During the study, all examined pegmatites were sampled and if adequately exposed, were mapped at a 1:200 scale. Maps of many of these showings do not exist in the literature. Emphasis was put on the mapping of the well known mineral collecting sites in Monteagle Township.

Pegmatites are generally considered to have crystallized from fluids somewhat enriched in incompatible (including lithophile) elements (e.g. Rb, Cs, Li, Tl, Pb, and B), which are not readily accepted into the crystal structure of most rock–forming minerals. These elements tend to concentrate in the melt until the final stages of crystallization. The crystal structure of muscovite and potassium feldspar provide a suitable host for the incompatible elements. Muscovite, however, unlike potassium feldspar, is not ubiquitous in all the pegmatites. In fractionated granitic pegmatites, as the concentration of these elements increases in the late melts, it also increases in the potassium feldspar that crystallizes from these late melts.

Comparison of the level of fractionation attained by various pegmatites should allow for the definition of distinct pegmatite fields or districts. This fractionation level can be assessed by the study of the concentration of the trace elements within the potassium feldspar crystal structure (Cerny 1982a). Coarse "megacrystic" potassium feldspar was studied because it is a mineral ubiquitous in granitic pegmatites and can be readily sampled and cleaned for analysis. The outer edge of the coarse blocky potassium feldspar in the intermediate (blocky potassium feldspar+quartz) zone was sampled. Potassium feldspars sampled from this position have the most elevated trace element abundances of any potassium feldspar obtained from a fractionated pegmatite (Jahns 1982). Thus, feldspars from this zone are well suited for the comparison of the fractionation level of pegmatites.

CURRENT PROGRESS

During 1988, sampling of the Perth/Verona area pegmatites was completed as was sampling and mapping of pegmatites in Murchison and Effingham townships. A cursory examination and concurrent sampling of the larger pegmatites in the Huntsville/Parry Sound and Mattawa areas was also undertaken. (Not all areas investigated in 1988 are shown on the location map). Approximately 200 potassium feldspar samples were submitted for geochemical analysis. No results have yet been received for any of these samples.

GEOCHEMISTRY

Geochemical results have been received for pegmatites examined during 1987 when pegmatites in Monteagle, Cardiff, Faraday, Dungannon, Monmouth, Miller, Bathurst, and Bedford townships were investigated.

Geochemical indicators such as K/Rb (mean value: 301), K/Cs (mean value: 8600), Rb/Cs (mean value: 36), and K/Ba (mean value: 395) suggest that extremely low levels of fractionation were attained by the pegmatites. Abundances of Li, Cs, and Rb are also extremely low making any subdivision of the various pegmatite fields quite arbitrary.

The pegmatites generally fall within the "Mica–Ceramic Bearing–Pegmatite Area" of Gordiyenko (1976) (Figure 51.2), defined by very high K/Cs ratios and a wide range of Na_2O values in the blocky potassium feldspar. Use of these diagrams requires reliable determinations of both high K and Cs values (Trueman and Cerny 1982). The extremely low Cs concentration in the feldspar of the present study area possibly makes this diagram somewhat unreliable; however, in conjunction with the low Li, Rb, and Ba content of the blocky potassium feldspar, the examined pegmatites appear to belong to Type 1B, i.e. the barren pegmatites of the mica–bearing provinces of Gordiyenko (1971) (Figure 51.3, 51.4, 51.5, and 51.6).

Figures 51.3 to 51.6 are based on Gordiyenko (1971) who published a series of plots which characterizes five pegmatite types based on the Cs, Rb, Li, and Ba content of the potassium feldspar and muscovite. The pegmatite types indicated are as follows:

1B barren pegmatites of the mica–ceramic–bearing provinces

1A barren pegmatites of rare element–bearing provinces

2 muscovite–feldspar pegmatites with Ba, Nb, Ta

3 spodumene–bearing pegmatites with Li, Be, Ta, (Nb, Sn)

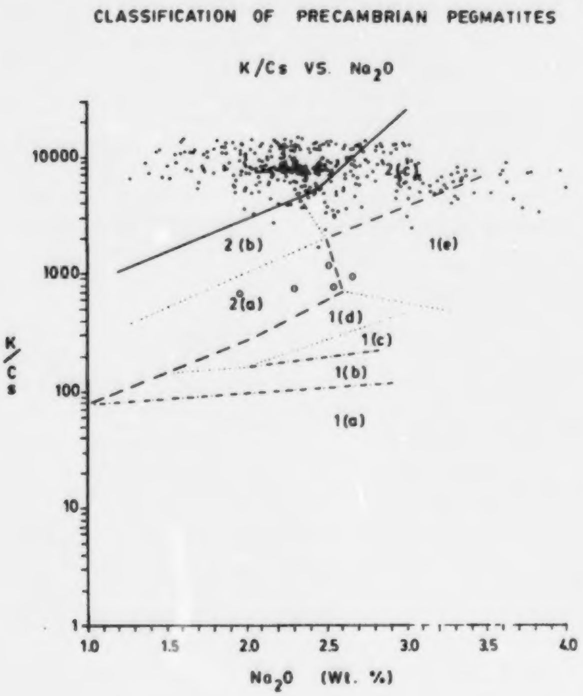

Figure 51.2. *Classification of Precambrian Pegmatites (Trueman and Cerny 1982) after Gordiyenko (1976) using K/Cs versus Na_2O composition of K-feldspar from granitic pegmatites. Key to pegmatite types shown in Figure 51.2:*
3-Mica-Ceramic (barren) pegmatites
2(c)-Barren, rare element-bearing pegmatites
2(b)-Beryl-bearing rare-element pegmatites
2(a)-Spodumene-bearing rare-element pegmatites
1(d)-Li, Be, Ta-bearing rare element pegmatites without pollucite
1(c), 1(b), 1(a)-Li, Rb, Cs, Be, Ta-bearing rare element pegmatites with pollucite
1(e)-Cs-bearing, barren pegmatites
Dots: Results from present study.
Open circles: Results from samples obtained at the Wal-Gem pegmatite in Lyndoch Township.

4 spodumene and lepidolite-bearing pegmatites with Li, Cs, Ta, Be, (Nb, Sn)

Lines ending at + mark in Figures 51.3 to 51.6 indicate range of arithmetic means with a 95% confidence level (Trueman and Cerny 1982).

DISCUSSION

The pegmatites occur as both zoned and unzoned intrusions. This development of a distinct and repeatable pattern of mineral assemblages or zones that occurs in pegmatites has been described by Cameron *et al.* (1949) and subsequently refined by Norton (1983). Most of the pegmatites in the project area are composed of the following rudimentary zones:

1. Border Zone–plagioclase+potassium feldspar+quartz±biotite±muscovite
2. Wall Zone–plagioclase+potassium feldspar+quartz
3. Intermediate Zone–potassium feldspar+quartz
4. Core Zone–quartz[1] (possibly very minor potassium feldspar)

Zoning in all of the pegmatites, where evident, is irregular and difficult to trace.

Contacts of many pegmatites, where exposed, vary anywhere from sharp intrusive contacts showing no sign of reaction (i.e. the Monteagle Township and Verona/Perth area pegmatites) to those that are distinctly gradational suggesting assimilation of the country rock along the contact of the pegmatites (i.e. the Dubblestein Showing in Bangor Township, Comet Quartz Occurrence in Murchison Township).

Pegmatites from within both the Central Metasedimentary Belt and the Central Gneiss Belt have been examined. The degree of metamorphism of the host rock does not appear to have any effect on the trace element composition of potassium feldspar in the pegmatites. It should be noted however, that the author studied an area of the Central Metasedimentary Belt where the metamorphic grade only attains greenschist facies metamorphism and where pegmatite occurrences are not common. Most of the pegmatites show no sign of deformation suggesting that they are post kinematic, however some, including the Fraser prospect in Glamorgan Township and possibly several of the syenite pegmatites in Cardiff Township, show signs of shearing and brecciation suggesting that they are possibly very late kinematic.

Ginsburg *et al.* (1979) suggests that barren, ceramic or monazite or allanite-bearing pegmatites or both (his so called "Pegmatites of Maximal Depth Formation") hosted in terranes of granulite facies metamorphism appear to be only controlled by metamorphic processes, such as partial melting. Cerny (1982b) expands these "maximal depth formation pegmatites" to cover pegmatites in upper amphibolite and granulite facies metamorphic terrains. The REE, Th, U, Nb, Ti, Zr-bearing pegmatites of southeastern Ontario appear to have formed by partial melting as suggested by the extremely low trace element content of the potassium feldspar, the lack of "exotic" Nb/Ta oxide minerals, lithium-bearing minerals etc., and accessory minerals typical of pegmatites occurring in high grade terranes of granulite

[1] In highly differentiated granitic pegmatites, the quartz zone is commonly not at the "core" of the pegmatite (Norton 1983); however, in the pegmatites in the study area, the quartz zone if present or exposed, always forms at the centre of the intrusion.

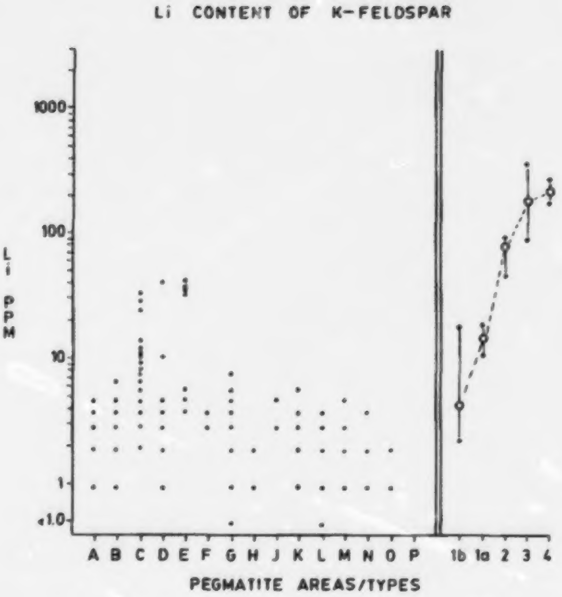

Figure 51.3. *Li content of K-Feldspar; of the 425 K-Feldspar samples analyzed, most contain less than 10 ppm Li and plot well within the area of Type 1B pegmatites (Trueman and Cerny 1982).*

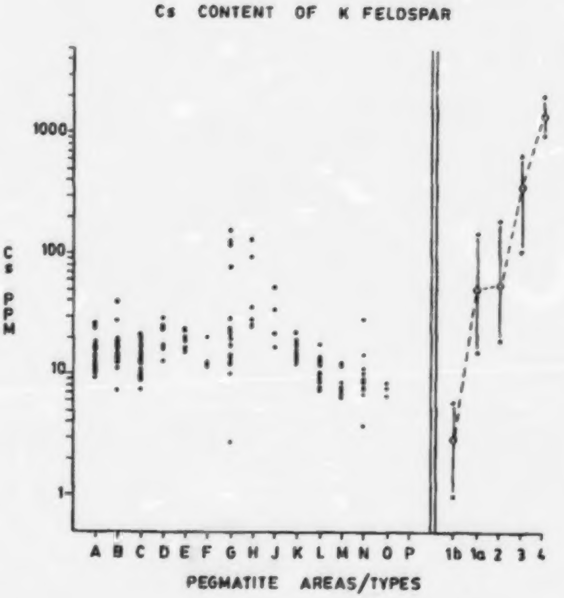

Figure 51.4. *Rb Content of K-Feldspar; Rb has a somewhat wider range; however, most of the samples contain less than 1000 ppm Rb and thus fall within the range of Type 1B pegmatites (Trueman and Cerny 1982).*

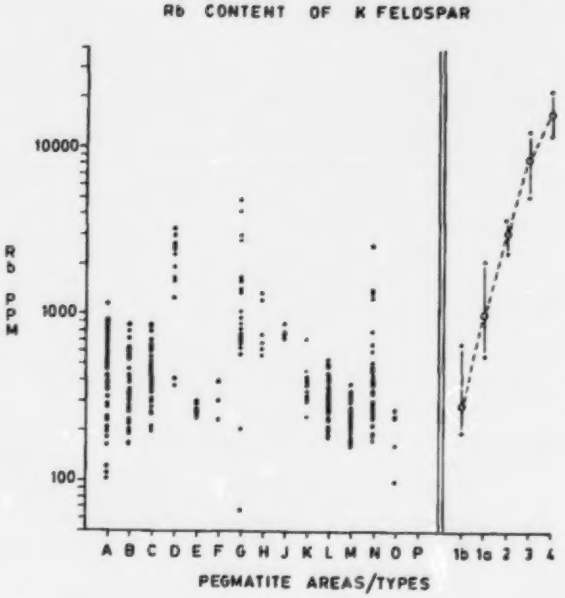

Figure 51.5. *Cs Content of K-Feldspar; Cs of K-Feldspar from pegmatites in mica-ceramic-bearing provinces contain less than 50 ppm Cs (Trueman and Cerny 1982). Most of the current data are well within this area.*

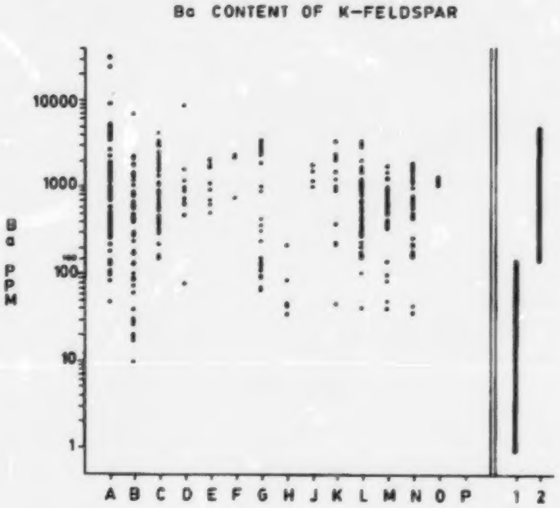

Figure 51.6. *Ba Content of K-Feldspar; Gordiyenko (1976) indicates that Ba content of K-Feldspar is a reliable distinguishing indicator of pegmatite provinces. Rare-element-bearing provinces have less than 150±50 ppm Ba. Mica-ceramic-bearing pegmatites contain more than 150±50 ppm Ba (Trueman and Cerny 1982). Most of the current data are within the mica-ceramic-bearing pegmatite range.*

to upper amphibolite facies metamorphism (quartz+feldspar±pyrite, tourmaline and beryl).

ECONOMIC POTENTIAL

The simple mineralogy of the pegmatites, i.e. quartz, plagioclase, potassium feldspar (±pyrite, tourmaline) and negligible to low and then only extremely local, REE, Ba, Nb, and Ta mineralization, the apparent lack of suitable adjacent "fertile" parent granitic intrusions, and the geochemistry of the potassium feldspar, all suggest that the pegmatites studied can be classified as ceramic and mica-bearing pegmatites (Gordiyenko 1971). These occur in high grade amphibolite to granulite metamorphic terranes and as such are not promising for potential rare-element (Nb, Ta, Rb, Cs, Li, Ba etc.) mineralization. Presently, the potential of these pegmatites as sources of feldspar, quartz, or uranium or as sources of thorium and REE is limited. This is because of their low content of allanite, uraninite, euxenite, monazite, and Nb/Ta oxide and because of their small size and irregular shape.

RECOMMENDATIONS FOR FUTURE MINERAL EXPLORATION

All of the pegmatites visited during this study are small and contain very sporadic REE, U, Th, and Ba mineralization; consequently, the prospects of developing significant reserves of these elements appear to be limited.

Several of the larger pegmatites, such as at the Richardson Mine, and Bathurst Mine, were developed prior to the advent of modern flotation technology. A re-evaluation of these occurrences is perhaps warranted despite the expenditures required to rehabilitate the existing pits.

The small size and lack of significant accessory mineralization renders most of the pegmatites of the Grenville of little interest to the mineral collectors. Several of the larger, better exposed and developed pegmatites, such as the MacDonald and Woodcox mines in Monteagle Township, are well known mineral collecting sites. There is good potential of finding additional sites of interest to the mineral collector.

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52. Geology of the Egan Chutes Provincial Park and Adjacent Areas, Bancroft

W.T. Grant

Drill Core Geologist, Ministry of Northern Development and Mines, Bancroft.

INTRODUCTION

The newly created Egan Chutes Provincial Park is situated along the York River, approximately 11 km east of Bancroft (Figure 52.1). The geology map (Figure 52.2) covers an area of approximately 1150 ha including the 340 ha park. This park is to be administered by the Ministry of Natural Resources as a Natural Environment Park. The park was created with the intention of providing the public with access to the York River and its three rapids: Egan Chute, Middle Chute, and Farm Chute (A,B,C on Figure 52.2); and to allow mineral collectors and geologists access to the interesting and varied geology of the area. The map shown in Figure 52.2 is largely a compilation of geology from Miller (1985) and Masson (1982). This author has conducted fill-in mapping and correlation of geology across the map boundaries. The mapping project is part of the ongoing program of the office of the Resident Geologist, Tweed.

MINERAL EXPLORATION

There have been three past producing quarries within the map area which have produced material for glass and pottery production (Hewitt and James 1955) from nepheline pegmatite. These are, from south to north, the Goulding–Keene, Morrison, and Davis quarries. The Goulding–Keene Quarry operated from 1937 to 1939 (Hewitt 1961) and produced approximately 10 000 tons of material. The Davis Quarry produced 1694 tons of nepheline pegmatite between 1939 and 1942 (Hewitt 1961). The Morrison Quarry produced 1663 tons of nepheline

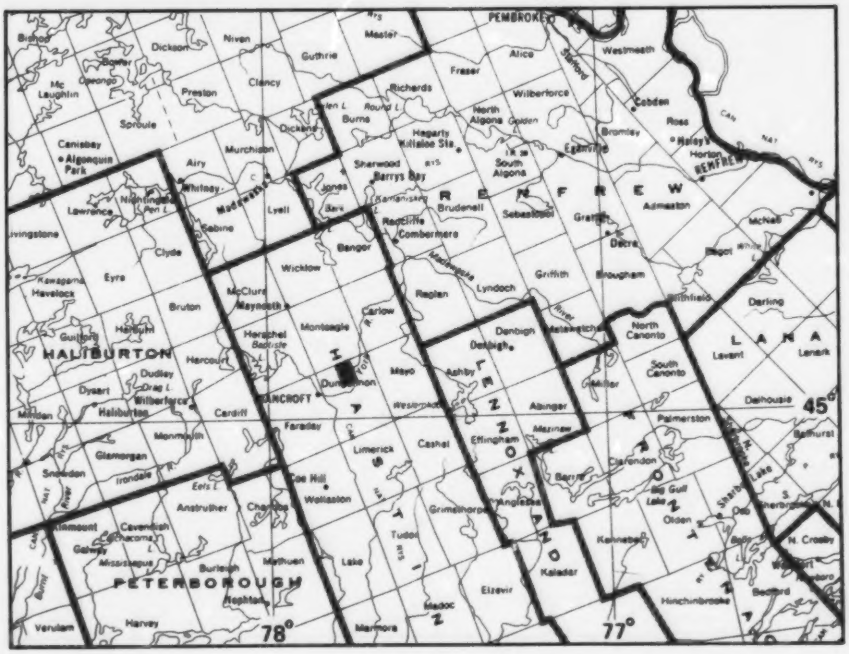
PEMBROKE
Westmeath
Cobden
Alice
Fraser
Wilberforce
Bromley
Ross
Horton
RENFREW
Admaston
McNab
Bagot
Darling
LANARK
Lavant
Lanark
Dalhousie
Bathurst
Palmerston
North Canonto
South Canonto
Clarendon
Barrie
Kennebec
Olden
Hinchinbrooke
Bedford
Kaladar
Elzevir
Madoc
Marmora
Lake
Tudor
Grimsthorpe
Cashel
Limerick
Wollaston
Methuen
Burleigh
Harvey
PETERBOROUGH
Anstruther
Chandos
Faraday
BANCROFT
Dungannon
Mayo
Herschel
Monteagle
Carlow
Wicklow
Bangor
McClure
Maynooth
Raglan
Lyndoch
Brudenell
Sebastopol
Griffith
Brougham
Denbigh
Ashby
Abinger
Effingham
Anglesea
HASTINGS
LENNOX
FRONTENAC
Cardiff
Monmouth
Glamorgan
Dudley
Dysart
Haliburton
Harcourt
HALIBURTON
Guilford
Harburn
Bruton
Eyre
Clyde
Havelock
Livingstone
Lawrence
Nightingale
Sabine
Lyell
Airy
Whitney
Madawaska
Murchison
Sproule
Canisbay
Algonquin Park
Mc Laughlin
Opeongo
Bower
Dickson
Preston
Niven
Clancy
Guthrie
Master
Richards
Burns
Hagarty
Killaloe Sta.
Sherwood
Barrys Bay
Jones
Radcliffe
Combermere
North Algona
South Algona
Eganville
Snowdon
Minden
Galway
Cavendish
Somerville
Verulam
Eels L.
Irondale
Coe Hill
Kennaway
Bishop
Dickens
York River
Madawaska River
78°
77°
45°

Figure 52.1. *Location map for the Egan Chutes Provincial Park. Scale 1:1 584 000 or 1 inch to 25 miles.*

CANADA ONTARIO

This project A.4.1 is part of the five year Canada–Ontario 1985 Mineral Development Agreement (COMDA), a subsidiary agreement to the Economic and Regional Development Agreement (ERDA) signed by the governments of Canada and Ontario.

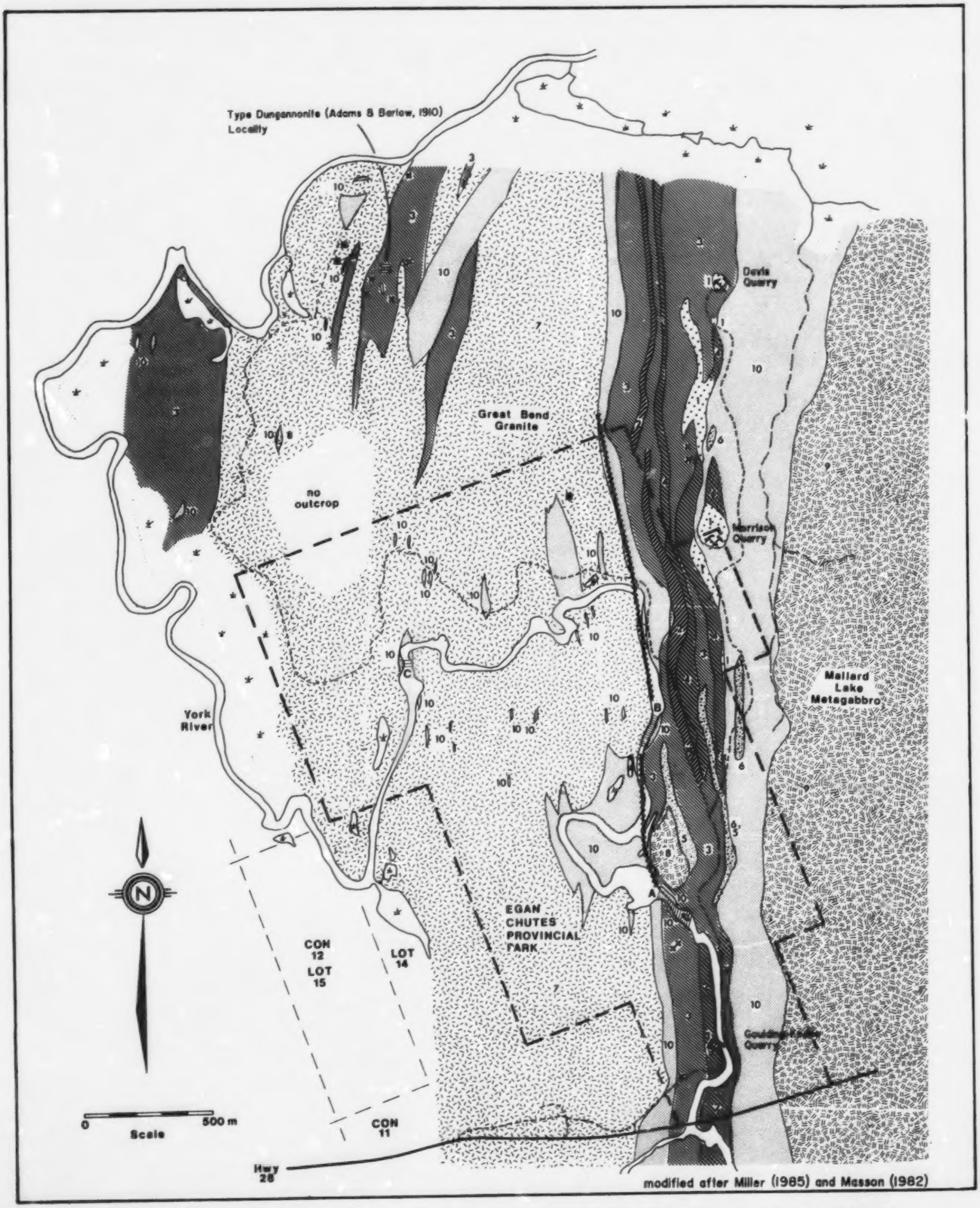
Type Dungannonite (Adams & Barlow, 1910) Locality
Great Bend Granite
no outcrop
Davis Quarry
Morrison Quarry
Mallard Lake Metagabbro
York River
EGAN CHUTES PROVINCIAL PARK
CON 12
LOT 15
LOT 14
CON 11
Goulding-Keene Quarry
A
B
C
N
0
500 m
Scale
Hwy 28
10
7
3
5
6
8
modified after Miller (1985) and Masson (1982)

Figure 52.2a. *Geological map of the Egan Chutes Provincial Park and adjacent areas. Geology largely derived from Miller (1985) and Masson (1982).*

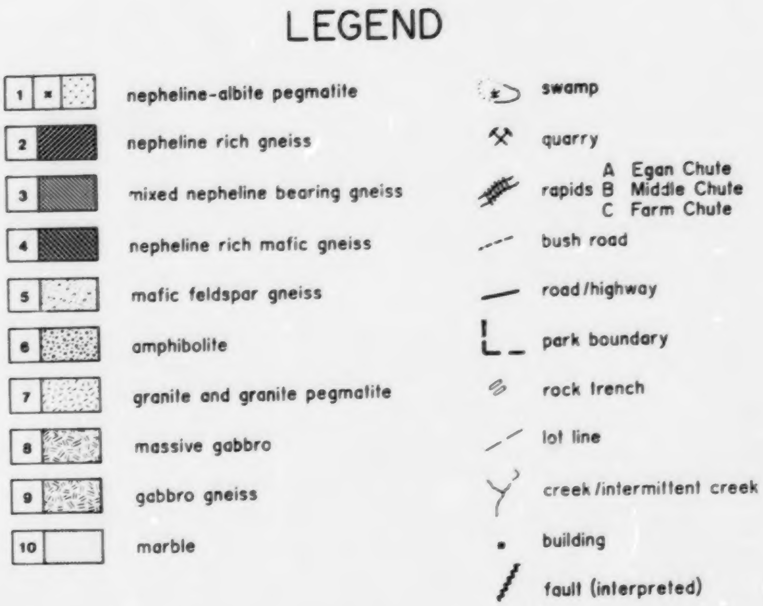
LEGEND
1 nepheline-albite pegmatite
2 nepheline rich gneiss
3 mixed nepheline bearing gneiss
4 nepheline rich mafic gneiss
5 mafic feldspar gneiss
6 amphibolite
7 granite and granite pegmatite
8 massive gabbro
9 gabbro gneiss
10 marble
swamp
quarry
rapids A Egan Chute B Middle Chute C Farm Chute
bush road
road/highway
park boundary
rock trench
lot line
creek/intermittent creek
building
fault (interpreted)

Figure 52.2b. *Legend for Figure 52.2a.*

pegmatite between 1939 and 1940 (Hewitt 1961). There has been no mineral production from the area since 1942. At one location north of the park boundary, in a zone of nepheline rocks, is a location referred to by Adams and Barlow (1910) as containing the type Dungannonite. At this location, several gem quality sapphires have been removed and appraised with a total of 64 carats being valued in 1981 at Cdn$680 (files of the Regional Mineral Specialist's Office, Bancroft). Presently, the major interest in the region is in mineral collecting. Mineral collecting in the Bancroft area is believed to contribute well over $1 million annually indirectly into the local economy.

GENERAL GEOLOGY

Egan Chutes Park is located near the northern boundary of the Grenville Province's Central Metasedimentary Belt. "The oldest rocks in the area are amphibolite, paragneiss, and marble all of which may have been replaced in part by nepheline syenite, syenite, granite, and gabbro. The Mallard Lake Metagabbro is interpreted to be the oldest intrusion. Later intrusions include nepheline rocks, syenites, and granites" (Hewitt and James 1956). The main geological feature is the north–trending nepheline syenite gneiss band. It is a relatively narrow band ranging in width from about 200 m to approximately 400 m. Within the nepheline syenite gneiss are numerous zones of nepheline–albite pegmatite which have crosscutting and conformable contacts of both a gradational and sharp nature. Narrow amphibolite zones occur within the nepheline gneisses, within the marbles, and adjacent to the gabbro bodies. The main nepheline gneiss is flanked both east and west by marble. The eastern marble zone is in contact with the Mallard Lake Metagabbro. The narrow marble band on the west of the nepheline gneiss band is bounded on the west by the Great Bend Granite. There are numerous occurrences of marble hosted within the Great Bend Granite. These range in size from only a few metres to several hundred metres. In the north–central portion of the map area is a zone of nepheline gneisses and marble which are hosted within the Great Bend Granite. At the extreme west of the map area are nepheline syenite gneisses with several small discontinuous marble pods hosted within.

A detailed description of all the rock units encountered in the map area is beyond the scope of this summary report. In the following, a somewhat more detailed account is given only on the nepheline–bearing rocks for which the area is well known (Miller 1985). (A detailed description of all rock units will be published in the near future in the marginal notes of a preliminary map of the area).

Nepheline–albite pegmatite and three types of nepheline–bearing gneisses occur in the area. The pegmatites are made up principally of nepheline and albite with minor amounts of potassium–feldspar, biotite, calcite, apatite, hackmanite, tourmaline, muscovite, pyrite, cancrinite, sodalite, and zircon (Reeve and Anderson 1976; Sylvester and Anderson 1976). Nepheline crystals measuring up to 1 m in diameter have been observed.

Amongst the nepheline–bearing gneisses, the "nepheline–rich gneisses" are characterized by their high nepheline (>50%) and albite contents. They generally have less than 15% mafic mineral content which may be made up of amphibole (hastingsite), biotite, garnet, magnetite, and pyroxene. They may also contain minor amounts of zircon, potassium-feldspar, scapolite, corundum, vesuvianite, titanite, muscovite, tourmaline, apatite, sodalite, cancrinite, hydronepheline, calcite, fluorite, and zeolite (Hewitt and James 1956).

"Mixed nepheline gneisses" consist of felsic gneisses interlayered with mafic gneisses; both varieties contain up to 50% nepheline. Corundum and sapphire have been found associated with these gneisses. The mafic minerals of these rocks are amphibole, biotite, garnet, and a number of minerals also observed in the "nepheline-rich gneisses" described above.

"Nepheline-rich mafic gneiss" contains approximately 30 to 50% nepheline and about 20% plagioclase. Mafic minerals are those described under "nepheline-rich gneisses" and make up about 30% of the rock.

GEOLOGICAL INTERPRETATION

The planned preliminary map is intended mainly as a guide for geologists and mineral collectors visiting the park. However, a short discussion of the various theories concerning the origin of the alkalic rocks is included for general interest.

There are two main theories for the formation of the nepheline-bearing gneisses in the map area. It was believed by Daly (1910) that these rocks were formed by metasomatism. By assimilation of carbonates in a subalkaline magma, a material results either abnormally rich in alkalies or one that has been desilicated to yield feldspathoids. Others since that time have proposed that the nepheline syenite gneiss originated from an igneous intrusion, possibly in a sill-like body (Miller 1985). Whatever hypothesis is favoured, one must consider several factors. The theory must explain the layered nature of the gneissic unit as defined by Baragar (1953). Baragar was able to divide the north-trending unit into members based on mineralogy, texture, and structure. Proponents of the metasomatic theory believe this to be evidence of layering in the original rock which was replaced.

At the present stage of his investigations, the author is not in a position to argue for or against any of the hypotheses on the origin of the alkalic rocks in the map area or the Bancroft area in general. The recent field investigations and the forthcoming preliminary geological map will hopefully lead to a renewed interest in the lithologies of the area by exploration companies and university departments.

The author will prepare for publication a generalized geological map of the Egan Chute Park indicating locations of interest to the mineral collectors.

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53. Geology and Beneficiation of Talc in the Tudor Formation, Southeastern Ontario

P.S. LeBaron

Geologist, Ontario Ministry of Northern Development and Mines, Tweed.

INTRODUCTION

A study of ultramafic–hosted talc occurrences in the Tudor Formation in Elzevir, Madoc, Grimsthorpe, and Cashel townships, initiated in 1987, was completed during the 1988 field season. Geological mapping was extended northward from the 1987 map area into Cashel Township. Beneficiation tests were done on diamond–drill core samples from three talc occurrences with good tonnage and grade potential, in order to determine milling procedures and problems, talc recovery, quality of the talc product, and potential commercial applications.

Limited geological mapping was done in Kaladar Township to examine a zone of altered ultramafic rocks similar to those in the Elzevir–Cashel Belt.

1988 SURVEY AREAS

Field work in 1988 was concentrated in the northern half of the Elzevir–Cashel Belt of talc occurrences along the western margin of the Weslemkoon Batholith. Access to the area is provided by a paved road from Highway 62 to Weslemkoon Lake, and by gravel forest access roads.

Several exposures of ultramafic rock in Kaladar Township were also briefly examined for their talc potential. These occur within 1500 m of the Lower (East) Flinton Road, between the Elzevir–Kaladar township line and Highway 41.

In addition to geological mapping, the survey included examination of diamond–drill core from several occurrences, whole rock geochemical analyses (by Lakefield Research), and thin section studies

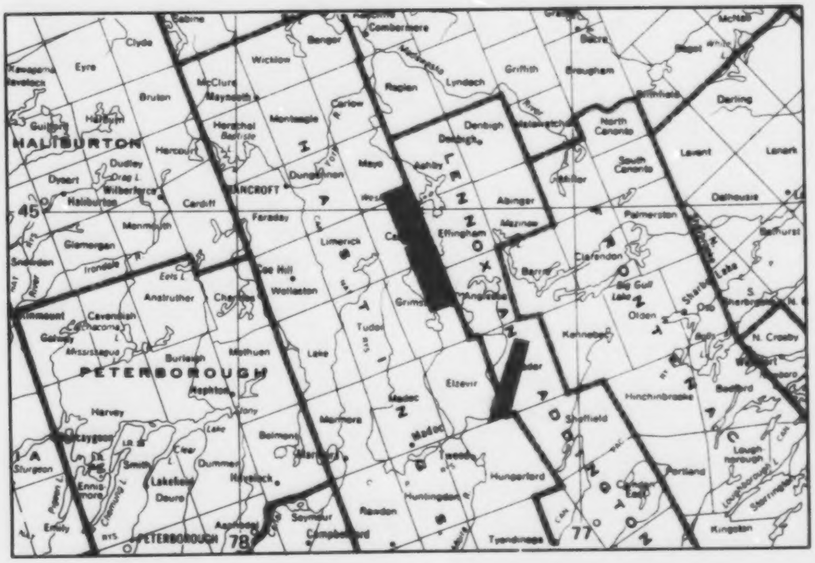
HALIBURTON
PETERBOROUGH
Eyre
Clyde
Bruton
Wicklow
Bangor
McClure
Maynooth
Herschel
Monteagle
Carlow
Raglan
Lyndoch
Griffith
Brougham
Darling
Denbigh
Ashby
Abinger
North Canonto
South Canonto
Lavant
Lanark
Dalhousie
Palmerston
Bathurst
Mayo
Dungannon
BANCROFT
Faraday
Limerick
Effingham
Clarendon
Barrie
Kennebec
Olden
Elzevir
Madoc
Tudor
Grimsthorpe
Wollaston
Coe Hill
Chandos
Anstruther
Methuen
Burleigh
Harvey
Dummer
Belmont
Marmora
Lake
Sheffield
Hinchinbrooke
Bedford
Hungerford
Huntingdon
Rawdon
Tyendinaga
Portland
Loughborough
Kingston
Seymour
Campbellford
Asphodel
Douro
Smith
Ennismore
Emily
Sturgeon
Lakefield
Havelock
Monmouth
Cardiff
Glamorgan
Dysart
Dudley
Harcourt
Guilford
Minden
Snowdon
Irondale
Cavendish
Galway
Harburn
Wilberforce
Haliburton
Eels L.
N. Crosby
45
78
77
PETERBOROUGH

Figure 53.1. *Location map of the study area. Scale 1:1 584 000 or 1 inch to 25 miles.*

This project A.1.2 is part of the five year Canada-Ontario 1985 Mineral Development Agreement (COMDA), a subsidiary agreement to the Economic and Regional Development Agreement (ERDA) signed by the governments of Canada and Ontario.

(by Hugh deSouza, Mineralogist, Ontario Geological Survey, Toronto).

REGIONAL GEOLOGY

The study areas lie within the Hastings Basin, a subdivision of the Central Metasedimentary Belt of the Grenville Province (Figure 53.1). The general geology of the Hastings Basin is described in LeBaron *et al.* (1987).

Geological maps covering parts of the study areas have been produced by Meen and Harding (1942), Hewitt and James (1955), Hewitt (1964), Lumbers (1968), and Wolff (1982).

MINERAL EXPLORATION

Mineral exploration in the area dates from the late 1800s, when iron, gold, copper, lead, and talc were discovered in Madoc Township. The level of exploration activity in the area has risen sharply over the past several years as a result of increased demand for industrial filler minerals such as wollastonite, talc, calcite, and mica, and new gold discoveries such as the Mono Gold Mines deposit in Madoc Township and the Noranda Exploration Company Limited property in Marmora Township.

GEOLOGY OF THE GRIMSTHORPE–CASHEL STUDY AREA

GENERAL GEOLOGY

The Grimsthorpe–Cashel map area (Figure 53.2) lies along the western margin of the Weslemkoon Batholith, a large trondhjemite–granodiorite body with a narrow, gabbroic to dioritic rim formed by assimilation of mafic volcanics by the intruding granitic magma (Lumbers 1968).

The metavolcanics which underlie northwestern Grimsthorpe Township and extend as a narrow (2 to 4 km wide) belt through central Cashel Township are dominated by mafic flows of the Tudor Formation. Felsic flows and pyroclastics of the Oak Lake Formation are interlayered with the mafic metavolcanics toward the western edge of the belt. Metasedimentary rocks, consisting of quartz–chlorite–biotite–amphibole assemblages, and rusty pyritic schists, occur throughout the metavolcanic sequence. Overlying the metavolcanics in western Cashel Township are clastic and chemical metasediments of the Mayo Group, predominantly marbles and calcareous sandstones and siltstones.

Although regional metamorphic grade in the Hastings Basin is greenschist facies, the study area lies within the amphibolite facies thermal metamorphic aureole of the Weslemkoon Batholith.

The area of interest is a zone about 300 m wide, within the mafic metavolcanics along the western margin of the batholith. Within this zone are several occurrences of ultramafic rock, altered to various assemblages of talc, serpentine, anthophyllite, chlorite, and carbonate. Some of these contain sufficient concentrations of talc (20 to 60 percent) to be considered potential talc ore. The mafic metavolcanics were classified in the field as tholeiitic basalt, komatiitic basalt, and ultramafic komatiite, based on alteration mineralogy, as described in LeBaron *et al.* (1987). A Jensen Cation Plot of 34 whole rock analyses from the map area supports the field classification of talc–anthophyllite–carbonate rocks as ultramafic komatiites within a predominantly iron–rich, tholeiitic volcanic sequence. Several samples plot as Mg–tholeiites and one as basaltic komatiite, but these are not traceable units at the scale of this survey.

The metavolcanics strike sub–parallel to the margin of the Weslemkoon Batholith and dip away from it to the west at 50° to 80°. The most prominent structure in the area is the Cashel Syncline, which probably developed during intrusion of the northern and southern lobes of the batholith. Small scale drag folding, locally prominent near the granodiorite contact, may also be related to the intrusion.

DESCRIPTION OF THE TALCOSE ZONES

Most of the talc occurrences are located north of the axis of the Cashel Syncline, as shown on Figure 53.2. Descriptions of the geology and previous exploration for several of the occurrences are given by Lumbers (1968) and by Dillon and Barron (1985).

The talcose zones vary in width from 5 to 30 m, averaging 15 to 40 percent talc, with the remainder being composed of varying proportions of anthophyllite, carbonate, chlorite, serpentine, and magnetite. Dimensions are difficult to determine because the talcose rocks generally form negative relief features, and are exposed intermittently along the sides of outcrop ridges bordering linear swamps. (A concentration of talcose boulders adjacent to a swamp along the axis of the Cashel Syncline north of Dafoe Lake may indicate talc mineralization in bedrock below the swamp.) Exposed widths of 15 m and lengths of 50 to 75 m are common, and the true extent of mineralization may be considerably greater. For example, the talc zone at the McMurray Occurrence (Location 2, Figure 53.2) was traced in outcrop for a strike length of 300 m before disappearing into swampy ground; a true width of about 40 m is indicated by diamond drilling.

The McMurray Occurrence offers the best exposure of a talcose zone within the map area. An area about 25 m by 7 m has been stripped and washed, and diamond drilling totaling 304 m in 17 holes over a 200 m strike length was done by David McMurray in 1982. The following description is based upon examination of the surface showing and

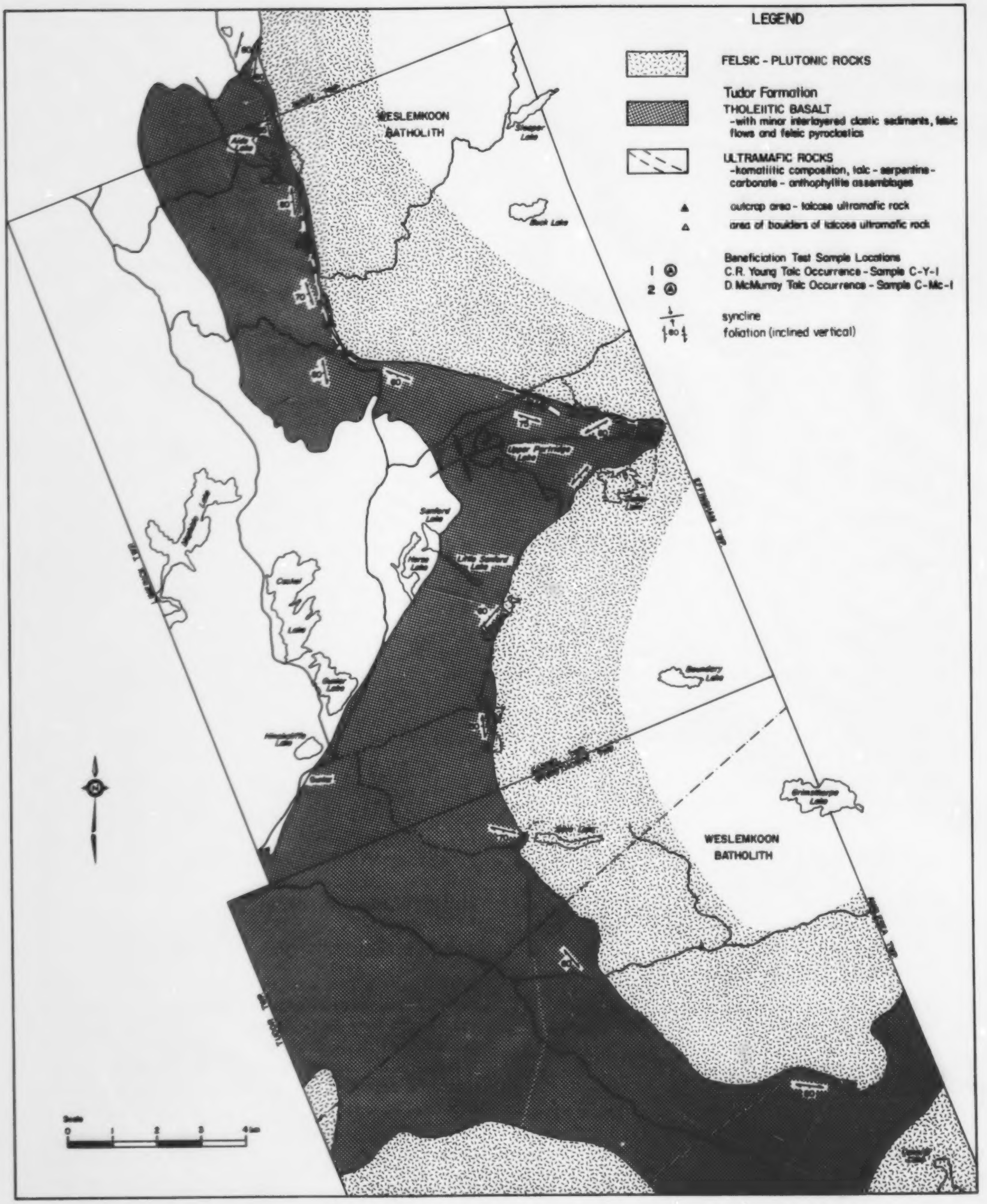
LEGEND
FELSIC - PLUTONIC ROCKS
Tudor Formation
THOLEIITIC BASALT
-with minor interlayered clastic sediments, felsic flows and felsic pyroclastics
ULTRAMAFIC ROCKS
-komatiitic composition, talc - serpentine - carbonate - anthophyllite assemblages
outcrop area - talcose ultramafic rock
area of boulders of talcose ultramafic rock
Beneficiation Test Sample Locations
1 C.R. Young Talc Occurrence - Sample C-Y-I
2 D.McMurray Talc Occurrence - Sample C-Mc-I
syncline
foliation (inclined vertical)
WESLEMKOON BATHOLITH
WESLEMKOON BATHOLITH
Buck Lake
Boundary Lake
Grimsthorpe Lake
Cashel Lake
Sandford Lake
Little Sandford Lake
Scale
0 1 2 3 4 km

Figure 53.2. *Simplified geology of parts of Cashel and Grimsthorpe townships, showing the distribution of talc–bearing zones within the Tudor Formation. Modified from Lumbers (1968) and Meen and Harding (1942).*

TABLE 53.1. MINERALOGY (VOLUME PERCENT) OF TEST SAMPLES, DETERMINED BY THIN SECTION POINT COUNTS AND X-RAY DIFFRACTION.

	M-Y-1	M-Y-1A	C-Y-1	C-Y-1A	C-MC-1	C-MC-1A	C-MC-1B
Talc	37	46	18	28	30	40	42
Dolomite	41	18	49	38	24	10	5
Calcite	–	–	–	–	24	20	1
Serpentine	19	29	11	9	16	11	33
Chlorite	1	5	–	1	3	13	1
Anthophyllite	–	–	21	23	–	1	3
Magnetite	2	2	1	1	3	5	15

diamond–drill core stored at the Bancroft Drill Core Library.

The McMurray zone consists of a series of ultramafic units from 2 to 10 m wide, separated by 20 to 40 cm wide bands of chlorite schist, biotite schist, and quartz–biotite schist. The ultramafic units consist predominantly of coarse, porphyroblastic talc–carbonate–anthophyllite rock and medium–grained talc–carbonate–serpentine rock. Very fine grained, dark green, chlorite–serpentine and buff talc schist occur as narrow seams within the ultramafic units. Mineral percentages for three samples of talcose rock are given in Table 53.1 (samples C–MC–1, C–MC–1A, and C–MC–1B).

To the north, between the ultramafics and the Weslemkoon Batholith, is banded, quartz–biotite–hornblende schist containing some pyritic bands which are represented by rusty schists in outcrop. Bordering the talcose zone to the south is a 3 to 5 m width of banded quartz–biotite–chlorite–hornblende schist overlain by fine–grained black amphibolite, which plots within the iron tholeiite field on a Jensen Cation Plot.

Similar descriptions of talcose zones as a series of altered ultramafic units separated by narrow bands of chlorite, biotite, or quartz–biotite schist are recorded in diamond–drill logs from other properties within the Elzevir–Cashel Belt (Twin Buttes Exploration, Canada Talc Industries, and C. Roger Young; Assessment Files, Resident Geologist's Office, Ministry of Northern Development and Mines, Tweed).

ORIGIN OF THE TALCOSE ZONES

The McMurray talc zone appears to be the result of alteration of a series of ultramafic komatiite flows underlain by fine–grained, clastic (possibly tuffaceous) metasediments and overlain by metasediments and tholeiitic metavolcanics. Thin bands of chlorite, biotite, and quartz–biotite schist between some of the ultramafic units represent interflow sediments. Primary textures within the ultramafics have been replaced by coarse porphyroblastic to fine schistose metamorphic textures. However, features which suggest an extrusive, rather than intrusive, origin for the ultramafics include: the conformable relationship of the ultramafics with adjacent lithologies, the occurrence of a number of ultramafic units of similar composition and thickness over a large lateral extent and limited stratigraphic interval, and the presence of thin metasedimentary layers between ultramafic units.

Some of the talc zones within the Elzevir–Cashel Belt may be altered komatiitic sills, but the similarity of other occurrences to the McMurray zone suggests that komatiitic flows are locally present throughout the belt and represent an extensive lower member of the Tudor Formation metavolcanics.

Hydrothermal alteration of the ultramafic rocks is associated with emplacement of the Weslemkoon and Elzevir Batholiths. Talc–serpentine–carbonate assemblages are produced when ultramafic rocks react with water, silica, and a small amount of carbon dioxide under low grade metamorphic conditions. With higher temperatures and greater carbon dioxide content of the hydrothermal fluids, talc is converted to anthophyllite by the reaction

7 talc = 3 anthophyllite + 4 quartz + 4 H_2O (Winkler 1976).

Anthophyllite–rich rocks formed within the medium grade metamorphic aureole of the Weslemkoon and Elzevir Batholiths have undergone late stage retrograde metamorphism, exhibiting radial aggregates of talc pseudomorphs after anthophyllite.

BENEFICIATION TESTS

SAMPLE DESCRIPTIONS

Beneficiation tests on samples of talcose rock from three occurrences within the Elzevir–Cashel Belt were done by I.M.D. Laboratories Ltd. in order to evaluate methods of extracting the talc, and to assess the quality of the talc product. Some of the test results are reported here, and further details will be reported in a forthcoming open file report.

The locations of two of the samples, C–Y–1 and C–MC–1, are indicated on Figure 53.2. The third sample, M–Y–1, is from the Cooper talc occurrence in Madoc Township, about 2.5 km southeast of the Village of Cooper (LeBaron *et al.* 1987). Each sample consisted of about 11 kg of split diamond–drill core.

Sample C–Y–1 is from a 12.8 m talcose section, excluding 2.6 m of anthophyllite–rich rock with less than 5 percent talc. The zone is at least 200 m long, consisting primarily of talc, dolomite, and anthophyllite. Sample C–MC–1, from the McMurray Occurrence, is a composite sample from two diamond–drill holes 150 m apart on the same talc zone. The rock is a complex assemblage of talc, dolomite, calcite, serpentine, chlorite, and magnetite. Sample M–Y–1 is from an 8.5 m section of core, composed primarily of talc, dolomite, and serpentine, which represents a part of the "Cooper East Zone", estimated to contain 780 000 tonnes of 30 to 33 percent recoverable talc (Meillon 1985). About 350 m west is the "Cooper West Zone", estimated to contain 2.2 million tonnes of similar grade material. The Cooper Occurrence is described in detail by Meillon (1985) and by Dillon and Barron (1985).

Thin sections of representative samples from each test sample were studied to obtain mineral percentages, shown in Table 53.1. An X–ray diffraction scan was also run for each sample to check mineral identification and to estimate calcite/dolomite ratios.

TEST PROCEDURE

Each sample was subjected to a series of five or six tests involving grinding of the sample, followed by multi–stage froth flotation. The first three tests investigated the effect of varying particle size under constant flotation conditions, while the remaining tests were done to improve results by modification of the flotation process (i.e. varying pH and reagents). The flotation stages in each test consisted of a rougher float, a scavenger float, and three cleaner floats. All flotation products were treated by low and high intensity magnetic separation and a chemical analysis was done on the best product from each sample.

TEST RESULTS

The best results with respect to talc yield and dry brightness for each of the three samples are shown in Table 53.2. A complete report on the tests, including geochemical analysis of the best products, has not yet been received. The dry brightness values for a sample of high quality commercial talc and Johnson's Baby Powder, taken from Kriens (1985), are included for comparison.

A comparison of talc yield with the talc content of each sample, as indicated by thin section study (Table 53.2), suggests that talc recovery is in the 75 to 90 percent range. Dry brightness is improved at the expense of talc yield, except in the case of sample C–Y–1 which shows the highest percent yield and brightness from the same test sample. The dry brightness values of samples M–Y–1 and C–Y–1 equal that of the baby powder and are close to the value for a high quality commercial talc, suggesting that talc from these zones has potential application in the production of house paints, cosmetics, and ceramics. Sample C–MC–1, with a lower dry brightness, may be suitable for industrial paints, plastics, caulks, and sealants. The mineralogy of the acid solubles remaining in the talc product (probably dolomite, magnesite, chlorite, and anthophyllite) may affect the potential applications.

The feed grades of about 30 to 45 percent talc for samples C–MC–1 and M–Y–1 are comparable to those of producing mines. Steetley Talc in Timmins operates at an average grade of 28 percent talc (J. Kriens, President, IMD Laboratories Inc., Concord, Ontario, personal communication, 1988).

KALADAR TOWNSHIP STUDY AREA

Figure 53.3 shows the geology in the area of Flinton Road, Elzevir and Kaladar townships. Flinton Group metasediments occupy a narrow, synformal structure between the Elzevir and Northbrook batholiths. Within the synform, between the Kaladar–Elzevir township line and the road from Flinton to Highway 41, are several exposures of ultramafic rocks.

These rocks show widespread alteration to talc–serpentine–carbonate–anthophyllite assemblages. The most common assemblage is anthophyllite–car-

TABLE 53.2. RESULTS OF FROTH FLOTATION TESTS ON SAMPLES OF TALCOSE ROCKS FROM MADOC AND CASHEL TOWNSHIPS. TALC YIELD IS THE WEIGHT OF TALC PRODUCT AS A PERCENTAGE OF ORIGINAL SAMPLE WEIGHT. TALC RECOVERY IS IN THE 75 TO 90 PERCENT RANGE.

Sample	Talc Yield (%)	Dry Brightness (%)	Acid Solubles (%)
C-Y-1-2	23.6	90.2	11.70
C-MC-1-1	29.2	88.7	5.73
C-MC-1-2	30.3	88.3	6.19
M-Y-1-4	46.8	88.0	9.92
M-Y-1-5	35.9	90.4	3.54
Commercial talc		91.2	
Johnson's Baby Powder		89.4	

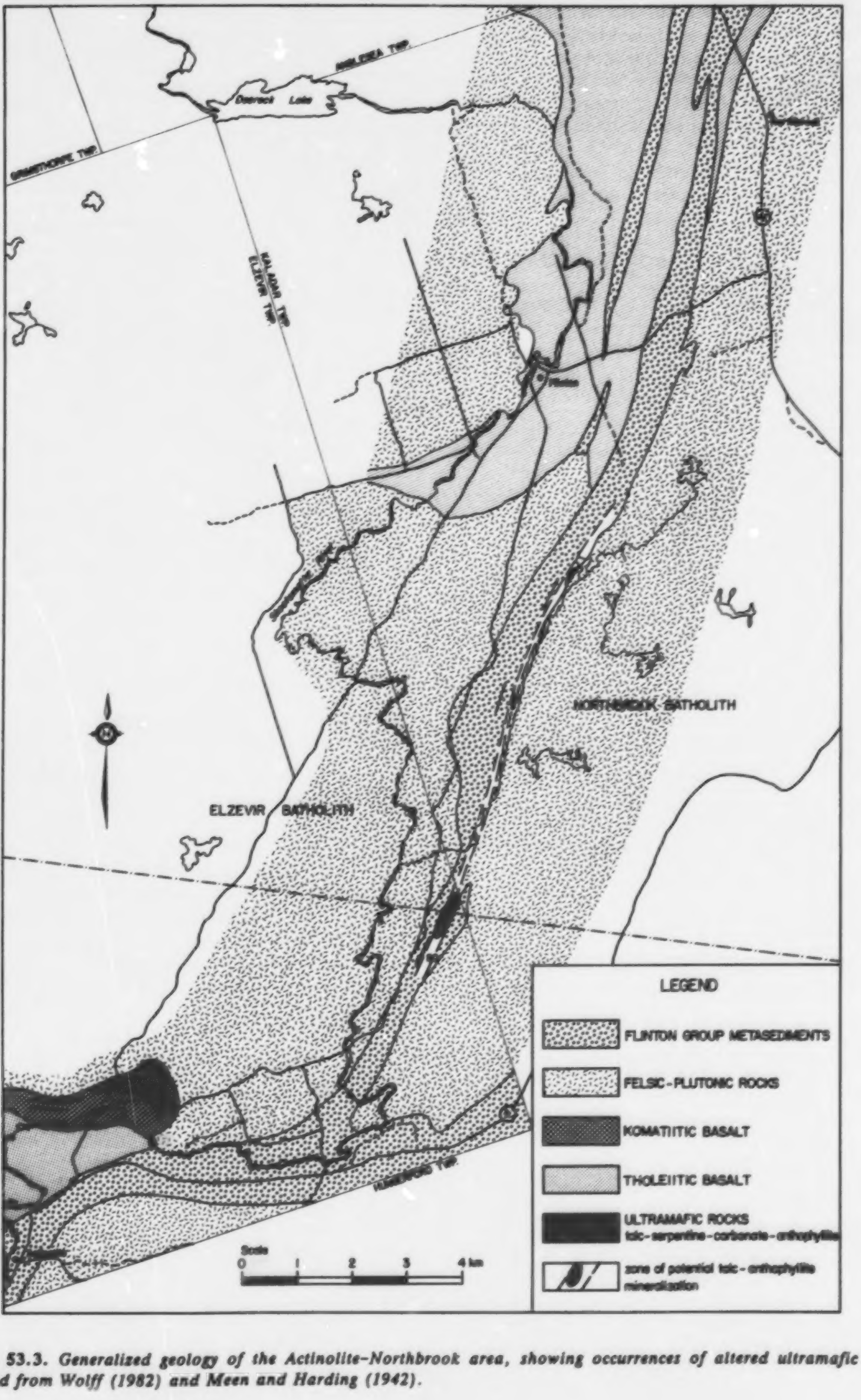
ANGLESEA TWP.
GRIMSTHORPE TWP.
KALADAR TWP.
ELZEVIR TWP.
NORTHBROOK BATHOLITH
ELZEVIR BATHOLITH
HUNGERFORD TWP.
LEGEND
FLINTON GROUP METASEDIMENTS
FELSIC-PLUTONIC ROCKS
KOMATIITIC BASALT
THOLEIITIC BASALT
ULTRAMAFIC ROCKS
talc-serpentine-carbonate-anthophyllite
zone of potential talc-anthophyllite mineralization
Scale
0
1
2
3
4 km

Figure 53.3. *Generalized geology of the Actinolite–Northbrook area, showing occurrences of altered ultramafic rock. Modified from Wolff (1982) and Meen and Harding (1942).*

bonate, in which 80 percent coarse rosettes of anthophyllite occur in a grey dolomite groundmass. Talc is pseudomorphic after anthophyllite, locally almost completely replacing the amphibole. Samples taken by Wolff (1982) and Verschuren *et al.* (1986) contain 78 and 60 percent talc, respectively.

Wolff (1982) correlates the ultramafic rocks with mafic volcanic rocks in the area, stating that the ultramafics may represent one of the oldest members of the Tudor Formation. They are similar in appearance and composition to ultramafic komatiites in Elzevir and Cashel townships. Diamond–drill core from a talc–anthophyllite–carbonate zone in lot 13, concession II, Kaladar Township (drilled by C.R. Young in 1981) shows that the zone consists of two ultramafic units about 7 m wide, separated by a 7 m wide section of chlorite–biotite and feldspar–biotite schist: a sequence similar to that observed at the McMurray Occurrence in Cashel Township.

The position of the ultramafic rocks within younger Flinton Group metasediments suggests tectonic emplacement. Thompson (1972) reports mylonite and strained quartz in adjacent metasediments as evidence of faulting along the margins of the ultramafic bodies. Linear swamps along the contact areas are additional evidence of possible faulting and should be considered as potential targets for talc mineralization within sheared margins of the ultramafics.

The ultramafic outcrop areas range in width from 5 m at the northernmost exposure on Figure 53.3, to 300 m near the Elzevir–Kaladar township line. The strike extent is obscured by overburden and may be more continuous than indicated on previous geological maps by Wolff (1982) and Thompson (1972).

SUMMARY

1. Altered ultramafic rocks in Elzevir, Madoc, Grimsthorpe, and Cashel townships locally contain sufficient amounts of talc to be of interest as potential talc ore.
2. The talc zones appear to be the result of alteration of ultramafic komatiite flows which represent one of the oldest members of the Tudor Formation. Komatiitic and tholeiitic basalts have also been identified within the metavolcanic sequence.
3. Preliminary results of beneficiation tests on samples from three talc zones within the Tudor Formation suggest that talc products of moderate to high quality can be obtained by multi–stage froth flotation.
4. A zone of altered ultramafic rocks in Kaladar Township, similar to those in the Elzevir–Cashel Belt, has potential for talc mineralization and should be considered as a talc exploration target.

ACKNOWLEDGMENTS

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54. Major Graphite Occurrences Within the Frontenac Axis, Southeastern Ontario

S.J. Black and A. MacKinnon

Geologists, Ontario Ministry of Northern Development and Mines, Tweed.

INTRODUCTION

The major graphite occurrences within the Frontenac Axis in Southeastern Ontario are located in an area of granulite facies metamorphic rocks within the Central Metasedimentary Belt of the Grenville Province (Wynne–Edwards 1972). The occurrences described in this report are all located within 10 km of the Westport–Canoe Lake Fault, a major structural feature that transects the Frontenac Axis from northeast to southwest, approximately 50 km north of Kingston. Although the close proximity of the occurrences to this fault may be important in their genesis, it is not the only controlling factor. The high regional metamorphic grade, the complex structure, and the location of major igneous plutons within the region also may have important roles in the formation of the graphite–enriched areas.

The objectives of the 1988 field work were to evaluate the regional geological setting and development potential of these occurrences and to determine domestic market opportunities for import replacement. The geological work reported here is a preliminary report based on compilation of assessment work and published company data and the preliminary results of field work carried out in 1988. The final results of the project will be presented in an open file report, planned for release in 1989.

Six major occurrences were investigated: the Globe Mine, 5 km south of Perth; the Cornell Property, 5.5 km east of Portland; the Timmins Property, 15 km southwest of Perth; the Burridge Marble Belt, 10 km west of Westport; the Desert Lake Property, 15 km northeast of Verona; and the Bawden Mine, 15 km east of Verona (Figure 54.1).

The major consumers of flake graphite are foundries and manufacturers of refractories, facings, and crucibles; other applications include lubricants, brake linings, and pencils (Anonymous 1987). The United States relies entirely upon imports for its consumption of natural graphite, which in 1986 totaled 38 100 tonnes (42 000 tons) (Taylor 1987). Some

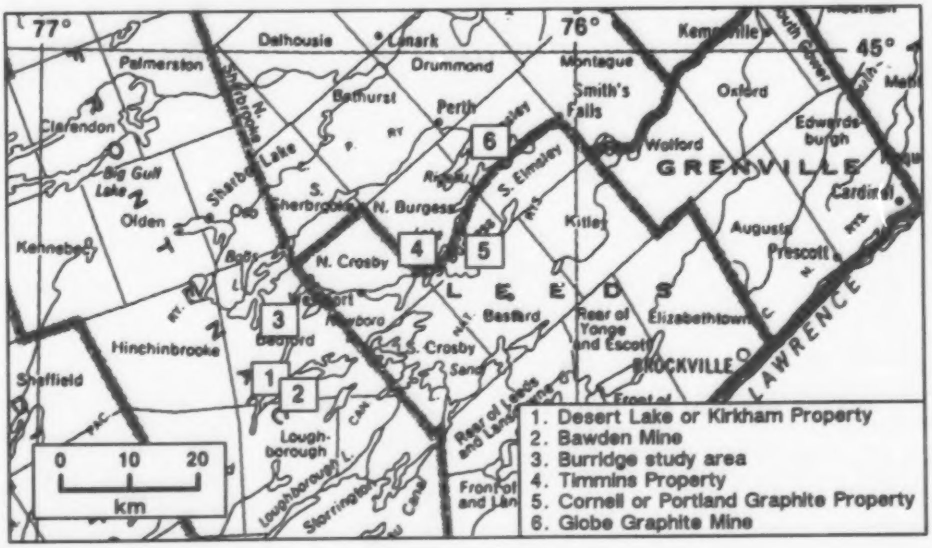
77°
76°
45°
Dalhousie
Lanark
Kemptville
Palmerston
Drummond
Montague
Smith's Falls
Oxford
Clarendon
N. Sherbrooke
Bathurst
Perth
Lake
6
Wolford
Edwardsburgh
GRENVILLE
Big Gull Lake
S. Sherbrooke
N. Burgess
S. Elmsley
Cardinal
Olden
Kitley
Augusta
Kennebec
N. Crosby
4
5
Prescott
L E E D S
Westport
3
Bastard
Rear of Yonge and Escott
Elizabethtown
Hinchinbrooke
Bedford
S. Crosby
BROCKVILLE
Sheffield
1
2
LAWRENCE
Loughborough
Storrington
Front of Leeds and Lansdowne
0 10 20
km
1. Desert Lake or Kirkham Property
2. Bawden Mine
3. Burridge study area
4. Timmins Property
5. Cornell or Portland Graphite Property
6. Globe Graphite Mine

Figure 54.1. *Location map of the graphite occurrences studied.*

This project A.1.3 is part of the five year Canada-Ontario 1985 Mineral Development Agreement (COMDA), a subsidiary agreement to the Economic and Regional Development Agreement (ERDA) signed by the governments of Canada and Ontario.

of this, to a value of $2 681 000 (M.A. Boucher, Analyst, Mineral Policy Sector, Department of Energy, Mines and Resources, Ottawa, personal communication, 1988), was then exported to Canada as graphite concentrate. Canada only produces graphite on an intermittent basis from a mine operated by Asbury Graphite Quebec Inc. located near Notre-Dame-du-Laus, Quebec (Prud'homme 1986).

Natural graphite occurs in three basic forms which are distinguished by their degree of crystallinity: amorphous, crystalline flake, and high crystalline (vein type). All occurrences examined during the present investigation are of the crystalline flake variety. There are, however, significant differences in the style, quality, and quantity of graphite in each deposit. The deposits can roughly be categorized into two groups: those with predominantly equidimensional flake graphite, and those characterized by significant concentrations of acicular flake (i.e. graphite flake with an aspect ratio of approximately 3:1 or 4:1) as well as of equidimensional flake. The Timmins, Burridge, Desert Lake, and Bawden properties fall into the first category, while the Globe and Cornell properties fall into the latter. Other differences and similarities among the deposits include host material, possible heat sources, confining mechanisms, and distribution of mineralized zones.

PROPERTY DESCRIPTIONS

GLOBE GRAPHITE MINE

The Globe Graphite Mine, located 5 km south of Perth, was first worked in 1870, and is the earliest worked graphite occurrence in the province. Since then, it has been operated by several companies. The mine was last worked in 1919, when it was developed to a depth of approximately 76 m (250 feet). Several companies have since completed exploratory work, the last being Black Gregor Explorations Ltd. which conducted diamond drilling and geophysics in 1984. Bell (1942) suggests that no more than 18 200 tonnes (20 000 tons) of graphite ore was mined from this deposit. Spence (1920) quotes the average graphite content of the ore milled from 1915 to 1918 as 8 percent. Bowdidge (1984) estimated that approximately 45 400 tonnes (50 000 tons) of approximately 7 percent graphite remain in the deposit below the mined-out portion to the 91 m (300 feet) level. He suggested if the mine were extended to the 305 m (1000 feet) level, an economic deposit might be proved.

The Globe deposit is located within an inlier of Grenville Supergroup rocks surrounded by Paleozoic Nepean sandstone. The deposit is hosted in crystalline marble and calc-silicates, and is in close proximity to quartzofeldspathic gneisses and granite. Lack of exposure, except in old mine openings, makes the construction of a detailed surface geological map very difficult. Bell (1942) described the graphite as associated primarily with siliceous zones within the marble, with the higher grade portions forming two lens-like bodies. The east lens had a strike length of 76 m (250 feet) and an average width of about 2.3 m (7.5 feet). The greatest exposed width was 3 m (10 feet), excepting the nearly 12 m (40 feet) thick intersection at the crest of an easterly plunging antiform at the eastern end of the pit. To the west, the zone narrowed to about 1.2 m (4 feet) for a distance of 21 m (70 feet),and then bulged to 2.4 m (8 feet) for a distance of 27 m (90 feet).

The graphite occurs in pyroxene- and amphibole-bearing marbles, and forms a band which is well-exposed in the main open pit, striking more or less east-west (Bowdidge 1984). The zone south of the pit is structurally complex, and at present remains poorly understood. Bowdidge (1984) reported that "drilling on the down-plunge extension of the main graphite zone has indicated that mineralization extends to a vertical depth of at least 91 m (300 feet). The thickness and grade is somewhat less that at the surface, where up to 12 m (40 feet) of 15 percent graphite was reported from the old workings".

Geophysical work suggests the possibility of additional nearby graphitic zones. Drilling of a geophysical anomaly a short distance to the south of the old workings confirmed the presence of several narrow, graphitic-bearing zones; however, they appear to have little economic value (Bowdidge 1984).

TIMMINS GRAPHITE PROPERTY

The Timmins Mine, located 15 km southwest of Perth, was operated on a small scale from 1917 to 1923 by Noah Timmins (Hawley 1988). Low demand after World War I resulted in closure of the mine. Sporadic exploration was carried out by several companies during 1942, 1951, and 1984. The most extensive work was that of Frobisher Limited in 1951, when 20 diamond-drill holes totaling 1231 m (4040 feet) were drilled on two graphite lenses 91 m (300 feet) and 137 m (450 feet) long, averaging 3.7 m (12 feet) in width. At that time, proven reserves were estimated at 227 000 tonnes (250 000 tons) of 8 percent graphite, with an additional 681 000 tonnes (750 000 tons) of probable reserves (R.G. Hawley, Field Manager, Lodi Metals Inc., personal communication, 1988).

The property is located in a geologically complex portion of the Central Metasedimentary Belt. The graphite is hosted in both crystalline calcitic and dolomitic marbles and in small areas of calc-silicate gneisses. This area of carbonate rock is bounded to the east and west by two large granitic plutons: the Westport and Rideau plutons. Small tectonic slices of granitic material are found in close association with the graphite-rich marbles throughout the property. The property is bounded to the north by a large area of migmatitic gneisses, indicative of the high regional temperatures attained in the rocks of this region. The graphite–rich zones consist predominantly of flake graphite hosted in crystalline marbles, although finer graphite in lenses in the marble locally grades up to 15 percent.

Recent mapping by Lodi Metals Inc. has identified several parallel zones of graphitic marble both south and north of the previously known deposit, and has extended the deposit a considerable distance to the east. The strike length of the deposit now totals at least 3000 m (10 000 feet) from east to west, with several individual zones totaling 610 m (2000 feet). The true width of the deposit, including country rock separating zones, is at least 1200 m (4000 feet). The zones of graphite–enriched marble are commonly 7.6 to 15.2 m (25 to 50 feet) wide, and usually have a vertical or near vertical dip.

This property may contain a considerably higher tonnage than was originally estimated by Frobisher Limited. However, this must still be confirmed by drilling.

Beneficiation problems encountered by Frobisher Limited in 1951, when samples of the Timmins ore were sent to the Black Donald Mill for testing (Hewitt 1965; Papertzian and Kingston 1982), could not be substantiated by Lodi Metals Inc. Hawley (1988) reported that no complicating factors, i.e. mica, were present in the graphite ore tested. The Timmins deposit is certainly worthy of further work, as it appears that a substantial deposit may be present.

CORNELL GRAPHITE PROPERTY

The Cornell Property, located 5.5 km northeast of Portland, was first discovered by John J. Cornell in 1934. Exploration activity on the site has been sporadic. The known deposit consists of a mineralized zone, in siliceous marble (Hewitt 1965), that has an average width of 31 m (100 feet) over a strike length of 580 m (1900 feet). The dip of the deposit is steep to vertical, with a grade of 10 percent over large parts of the mineralized zone (Papertzian and Kingston 1982). Locally, this grade could be as high as 20 percent. The country rock surrounding the deposit is characterized by siliceous marbles and paragneiss. The possibility of additional parallel zones of graphite–enriched marble is currently being investigated by the present operator of the site, Victoria Graphite Ltd.

The graphite occurs as disseminated flakes averaging 1/8 inch in size (Hewitt 1965). Some of this flake has a high aspect ratio, i.e. 4:1; however, it appears that this will readily break down to a finer equidimensional flake during milling. The grade and possible extent of this deposit warrant further exploration.

BURRIDGE MARBLE BELT

The Burridge marble belt is located approximately 15 km northeast of Godfrey, and 10 km west of Westport. This is a large area of crystalline marble that extends over a distance of at least 10 km. The present investigation involved geologic reconnaissance mapping (at 1:10 000 scale) of the southern half of the belt, covering an area approximately 5 km². There has been to date no active exploration for graphite in this area, although several promising occurrences have been noted (Sabina 1983). This region is characterized by a very clean, coarse, crystalline, calcitic marble with a low graphite content, commonly less than 1 percent. In the southwestern part of this region, however, several zones of graphite–enriched calcitic crystalline marble were noted. The grade varies, but is commonly 3 to 5 percent graphite. Several occurrences of large, equidimensional flake, up to 6 to 8 mm in diameter, were observed. This could be due to the influence of granitic gneiss, a short distance to the west, as well as to faulting, which could act as a concentrating mechanism for the graphite. Elsewhere in the belt, these features are lacking, possibly explaining the lower graphite grades.

Insufficient work has been completed to date on this belt to accurately assess its potential; however, the presence of large flake over a large area is promising.

DESERT LAKE AND BAWDEN PROPERTIES

These properties are located approximately 15 km east of Verona; both are currently being investigated by Stewart Lake Resources Inc. The Desert Lake Property is located near the northern end of Desert Lake, and the Bawden Property is on the northern shore of Birch Lake, 2.5 km to the southeast. The present survey involved reconnaissance mapping (at 1:10 000 scale) of an area approximately 2 km² between Desert and Birch lakes. The purpose of this work was to obtain a greater understanding of the geological structure and thus enhance development opportunities for graphite in the region.

The Desert Lake deposit was first worked by Frobisher Limited in 1952 (Edwards 1953), when 30 diamond–drill holes totaling 3000 m (9860 feet) were drilled and two lenses of graphite mineralization were outlined. Hewitt (1965) described the graphite as occurring "in a synclinal structure in the Grenville marble–paragneiss–quartzite sequence. The syncline plunges northeast at 25 degrees and is overturned to the west so that the west arm dips eastward at about 45 degrees, and the overturned east arm dips eastward to about 70 degrees. The graphite flake occurs in a highly silicated marble at the contact with the overlying siliceous paragneiss and quartzite. Pyritic quartzite and paragneisses form the centre of the syncline which is underlain by silicated marble. The graphitic ore zone occurs in marble at the quartzite–marble contact of both arms of the syncline."

Papertzian and Kingston (1982) noted that "the deposit occurs no more than 152 m (500 ft.) from the Canoe Lake–Desert Lake Fault Zone, which is a major transcurrent (thrust) Precambrian fault. Granite or granitized sediments occur on the opposite side of the fault and the immediate area of high grade mineralization is cut by pegmatite stringers". The close proximity of the Canoe Lake–Desert Lake Fault is evident from the underground workings at the Desert Lake property. Large areas of marble breccia were observed along the boundaries of the ore zones. Exploration work completed by Stewart Lake Resources Inc. has partially delineated three mineralized zones and identified 12 other geophysical anomalies which are as yet untested. The main zone, which is open at both ends and at depth, contains 4.5 million tonnes (5 million tons) of drill–indicated reserves, averaging 7.6 percent graphite (The Northern Miner 1988).

The Bawden Mine may be considered an eastern extension of one of these zones; however, the mineralization does not appear to be extensive. The property was first worked in 1890. The graphite occurs as disseminated flakes within a crystalline marble. The ore grades up to 20 percent graphite (Papertzian and Kingston 1982); however, the overall average grade is about 5 to 8 percent.

CONCLUSIONS

Six major graphite occurrences near the Westport–Canoe Lake–Desert Lake Fault were examined during the 1988 field season. Of these, four are currently undergoing active exploration. The Timmins, Burridge, Desert Lake, and Bawden occurrences all contain significant quantities of flake graphite hosted in crystalline marble and calc–silicates. The Globe and Cornell properties are hosted in siliceous marbles, and have appreciable quantities of "needle" graphite as well as equidimensional flake. The structural styles of the deposits differ markedly. The Globe, Bawden, and Desert Lake deposits are found in close association with tightly folded (synformal) structures. The Cornell and Burridge properties are found within a large series of parallel marble bands. The Timmins property is unique in that it is close to two major plutons. These factors could all have a bearing on the style of deposit and the grade of the graphite. All of the deposits can be considered to be of economic interest.

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55. Structural Geology of the Madoc Fluorite Area, Southern Ontario

L.G.D. Thompson[1] **and D.A. Williams**[2]

[1]Geophysicist, Ontario Ministry of Northern Development and Mines, Tweed.

[2]Geologist, Ontario Ministry of Northern Development and Mines, Tweed.

INTRODUCTION

The work reported here is a continuation of a program to study the structural and stratigraphic setting of fluorite veins in the Madoc area (Williams and Thompson 1986; Thompson and Williams 1987) (Figure 55.1). The fluorite veins occur above and below the Precambrian–Paleozoic unconformity in the Madoc area, and their localization has been influenced by normal faults. Earlier work in the project, including geological mapping, stratigraphic measurements, and geophysical surveys, has concentrated on locating faults and determining how they offset stratigraphy.

In 1988, field work was carried out in parts of Marmora, Rawdon, Madoc, and Huntingdon townships. The geological work was to determine the pattern of mineralized fractures. The purpose of the geophysical work was to complete the geophysical investigation of fault zones located at the O'Hara Mill site (Thompson and Williams 1987, p.320–321), 4 km northwest of Madoc (Figure 55.2). This report concentrates upon the results of the geophysical work.

STRUCTURAL GEOLOGY

This year's field examination of the fluorite-bearing veins has resulted in a more accurate determination of the pattern of mineralized fractures (Figure 55.2). Veins occupy fractures belonging to two joint sets, one striking approximately 115° and the other approximately 140°. Any individual vein generally shows very little variation in strike. However, one of the Lee Senior veins (*see* Figure 55.2) is characterized by an abrupt change in strike, indicating that it occupies fractures belonging to both joint sets.

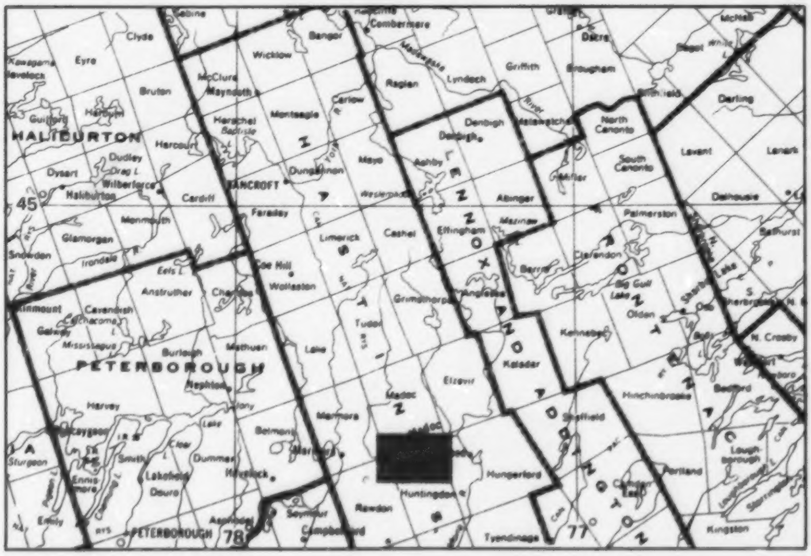
HALIBURTON
PETERBOROUGH
HASTINGS
FRONTENAC
LENNOX AND ADDINGTON
Clyde
Eyre
Bruton
Harburn
Guilford
Havelock
Harcourt
Dudley
Dysart
Haliburton
Wilberforce
Cardiff
45
Monmouth
Glamorgan
Snowdon
Irondale
Eels L.
Anstruther
Chandos
Cavendish
Galway
Mississagua
Burleigh
Methuen
Harvey
Smith
Dummer
Belmont
Lakefield
Douro
Ennismore
Emily
Sturgeon
PETERBOROUGH
78
Asphodel
Seymour
Campbellford
Sabine
Wicklow
McClure
Maynooth
Herschel
Monteagle
Bancroft
Dungannon
Faraday
Limerick
Coe Hill
Wollaston
Lake
Tudor
Marmora
Madoc
Rawdon
Huntingdon
Bangor
Combermere
Raglan
Carlow
Mayo
Wesleymach
Cashel
Grimsthorpe
Elzevir
Lyndoch
Griffith
Brougham
Denbigh
Ashby
Abinger
Mazinaw
Effingham
Anglesea
Kaladar
Sheffield
Hungerford
Tyendinaga
77
Camden East
Dacre
Blithfield
North Canonto
South Canonto
Miller
Palmerston
Clarendon
Barrie
Big Gull Lake
Olden
Kennebec
Hinchinbrooke
Portland
Loughborough
Kingston
Darling
Lavant
Lanark
Dalhousie
Bathurst
S. Sherbrooke
N. Crosby
Bedford
McNab
Sharbot Lake

Figure 55.1. *Location map for the Madoc Area, Southern Ontario. Scale: 1:1 584 000 or 1 inch to 25 miles.*

This project A.1.4 is part of the five year Canada-Ontario 1985 Mineral Development Agreement (COMDA), a subsidiary agreement to the Economic and Regional Development Agreement (ERDA) signed by the governments of Canada and Ontario.

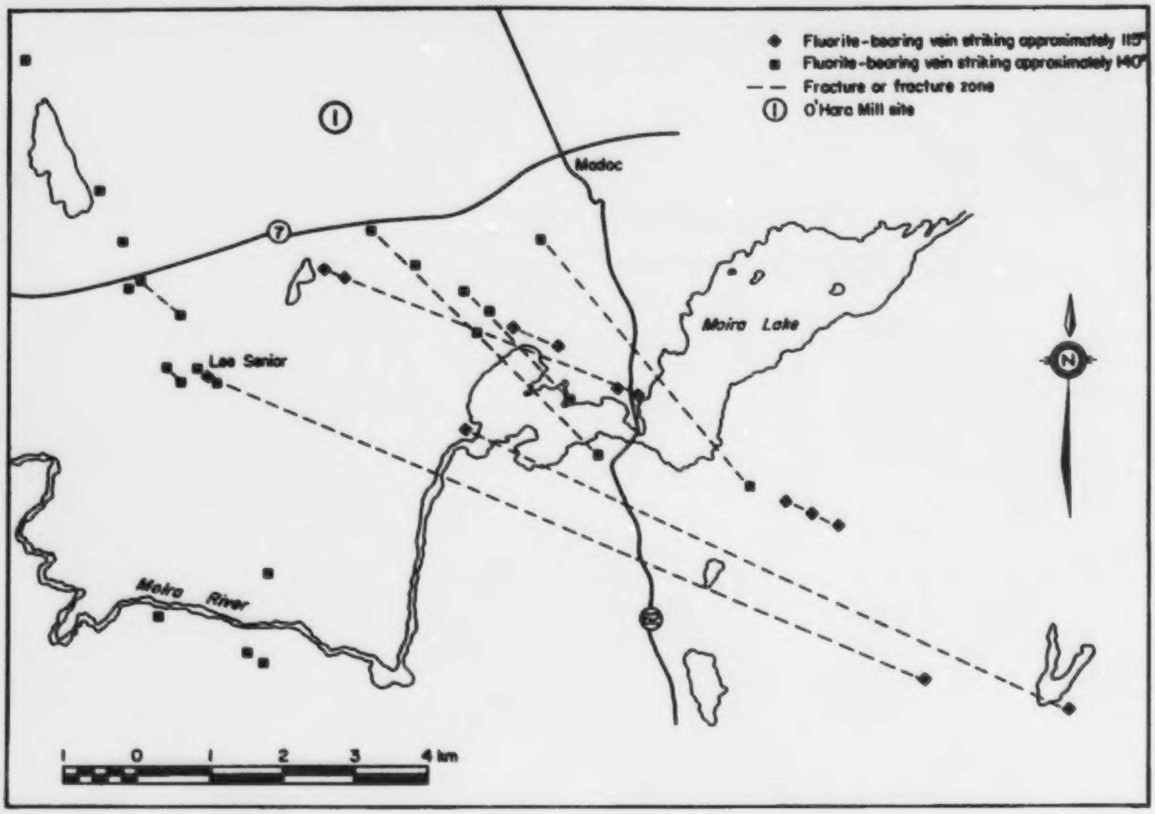
◆ Fluorite-bearing vein striking approximately 115°
■ Fluorite-bearing vein striking approximately 140°
— — Fracture or fracture zone
① O'Hara Mill site
①
Madoc
7
Moira Lake
Lee Senior
Moira River
N
1 0 1 2 3 4 km

Figure 55.2. *Map of the study area showing fractures occupied by fluorite-bearing veins.*

Except for some of the western veins, fractures or fracture zones are known to contain more than one vein deposit along their lengths and are traceable for up to 11 km.

GEOPHYSICAL SURVEYS

The fluorite deposits that have historically been of most economic significance are located close to junctions between faults (Thompson and Williams 1987, p.318). The O'Hara Mill site (Figure 55.2) is one of five sites originally selected for geophysical investigation as part of the study of the Madoc fluorite deposits (Thompson 1986; Thompson and Williams 1987). The main survey line extends 1320 m in an east–west direction along the 5–6 sideroad between Concessions III and V in Madoc Township. A short line of 600 m runs south to north along the Concession IV road perpendicular to the main line.

Geophysical field work in 1986 located a major fault, between Paleozoic limestone on the west and Precambrian mafic metavolcanic rock on the east, at the western end of the main survey line at the O'Hara Mill site (Williams and Thompson 1986). Field work in 1987 indicated another fault in the Precambrian in the vicinity of the Concession IV road (Thompson and Williams 1987). Also in 1987, a thin layer of sandstone of the Shadow Lake Formation was discovered overlying the Precambrian rock on the eastern side of this indicated fault. The presence of the sandstone made this site of significance to the COMDA unconformity project (*see* DiPrisco, this volume). Therefore, a complete investigation of the O'Hara Mill site, using all available geophysical methods, was considered important.

Geophysical work at the O'Hara Mill site (not previously reported), and the year of its completion, includes:

1. total field magnetic measurements over the main fault zone at the western end of the east–west survey line (1988),
2. repeat seismic refraction spreads along the eastern part of the east–west survey line and along the north–south survey line (1988),
3. alpha meter measurements over the indicated fault zone along the east–west survey line in the vicinity of the Concession IV road (1988),
4. resistivity measurements (converted to conductivity values) over the indicated fault zone along

the east–west survey line in the vicinity of the Concession IV road (1988),

5. gravity measurements along both survey lines, including a precise elevation survey along both roads (1988). This work was done by the Geophysics/Geochemistry Section of the Ontario Geological Survey, Toronto.

6. density measurements (1988) of four samples of Precambrian mafic metavolcanic rock from the O'Hara Mill site area (average density 2.79 gm/cc), eight samples of various Precambrian marbles from the areas south, east, and northeast of the O'Hara Mill site (average density 2.75 gm/cc), and six samples of the Shadow Lake sandstone from the eastern part of the O'Hara Mill site (average density 2.60 gm/cc).

7. numerous auger holes along both survey lines (1986, 1987, 1988). Short holes hit boulders; most holes hit the water table or bedrock.

8. a back–hoe test pit at about 978 m on the east–west survey line, where the Precambrian rock was closest to the surface. The pit showed 1.0 m of clay and 2.5 m of weathered sandstone layers, and bottomed on a hard, competent layer of red sandstone. The Precambrian basement was not reached.

9. conductivity measurements over the western part of the east–west survey line (1986).

O'HARA MILL SITE RESULTS

The results of all geophysical field work done at this site are summarized in Figures 55.3a, 55.3b, and 55.3c. Figure 55.3a includes the western part of the east–west survey line, from 0 to 700 m, and Figure 55.3b includes the eastern part of the same line, from 700 to 1320 m. Figure 55.3c includes the Concession IV road survey line from 0 to 600 m.

In Figure 55.3a, the major fault between the Paleozoic limestone and the Precambrian mafic metavolcanic rock is shown at the extreme left (west) side, at about 100 m on the survey line. The seismic results and auger holes show that the overburden above bedrock is clay, both above and below the water table.

In Figure 55.3b, the fault in the Precambrian basement is identified at about 850 m on the survey line, just west of the Concession IV road. The overburden above the Precambrian bedrock west of the fault is clay. East of the fault zone, a thin layer of Shadow Lake sandstone overlies the Precambrian basement. An auger hole at 896 m bottomed in Shadow Lake sandstone at 2.8 m, but an auger hole just to the west, at 880 m, was still in clay at 4 m. This suggests that the Shadow Lake sandstone terminates at the fault.

Other evidence of a change in the Precambrian basement is a rise in the basement to a peak at about 880 m, with a change in the Precambrian surface topography from irregular knolls to a relatively flat-lying surface. Also, the seismic velocity of the Precambrian changes at the fault from about 5000 to

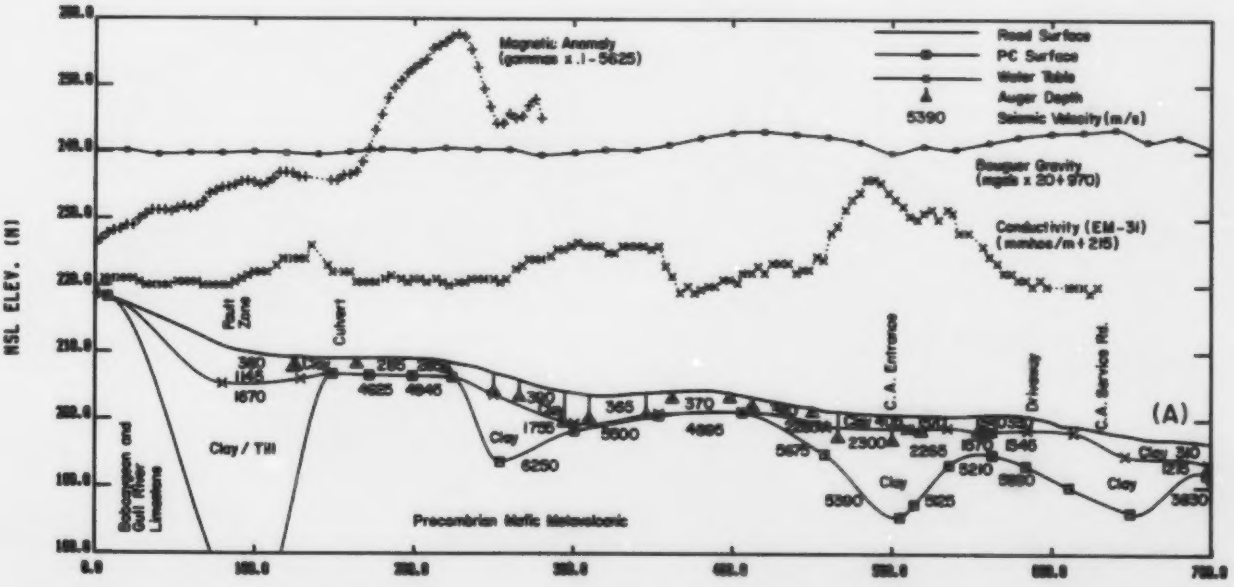

Figure 55.3a. *Geophysical survey results for the O'Hara Mill site: along the 5–6 sideroad, from west to east (western part);*

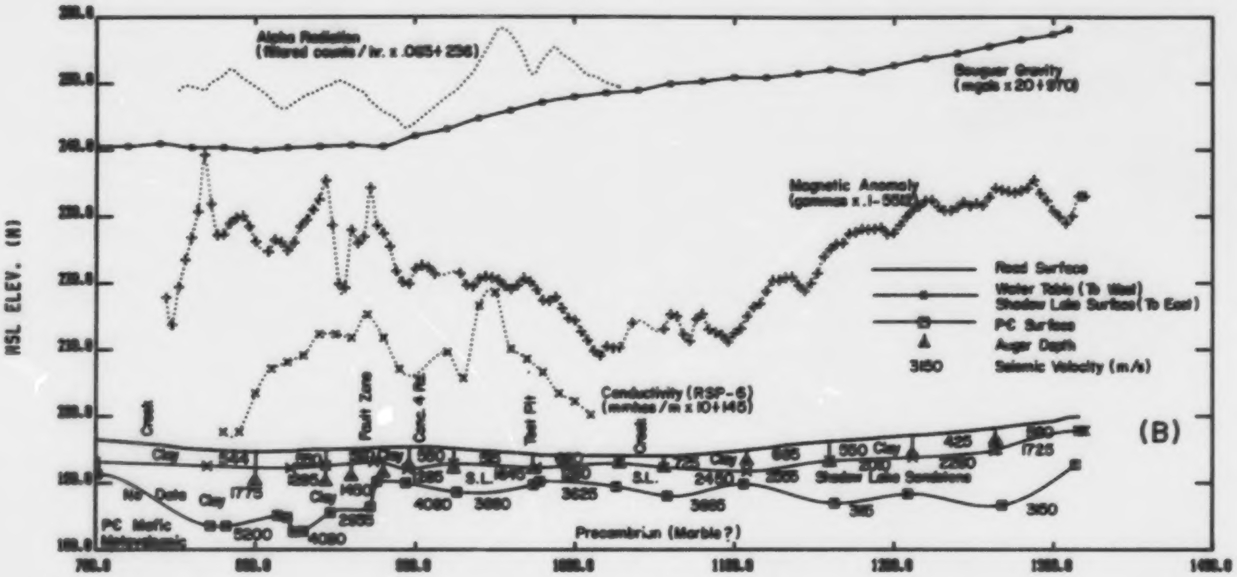

Figure 55.3b. *Geophysical survey results for the O'Hara Mill site: along the 5-6 sideroad, from west to east (eastern part);*

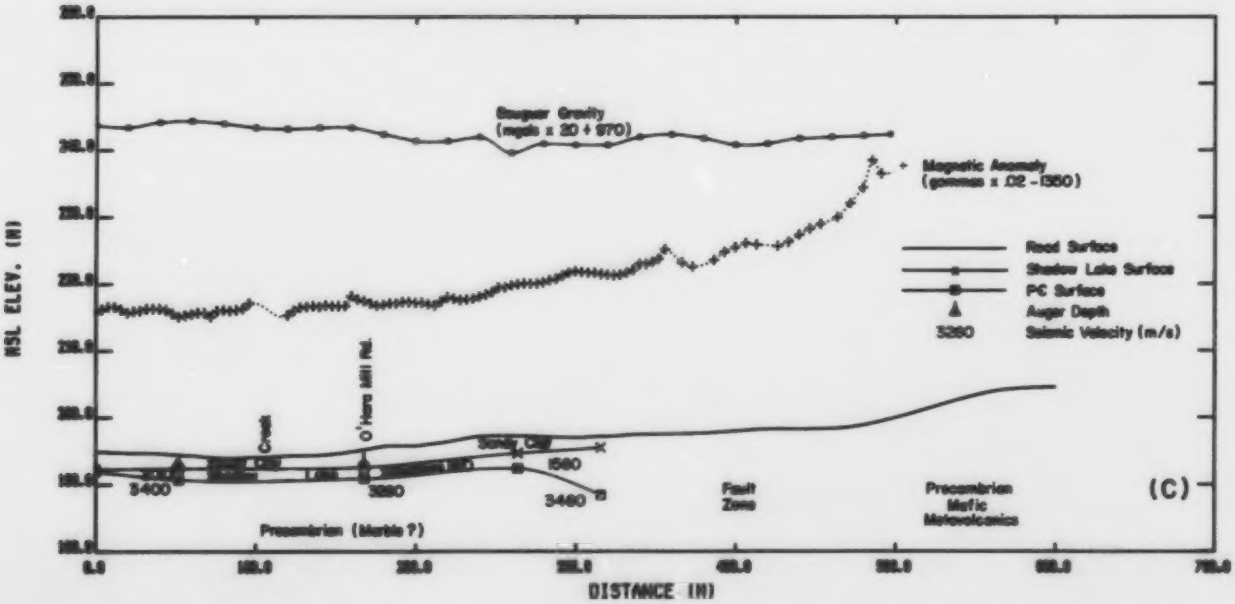

Figure 55.3c. *Geophysical survey results for the O'Hara Mill site: along the Concession IV road, from south to north.*

6000 m/s (mafic metavolcanic rock) to about 3000 to 4000 m/s. This indicates a different Precambrian rock type east of the fault. Although the test pit at 978 m did not reach the Precambrian basement, the Precambrian rock east of the fault is probably marble. This conclusion is based upon the following reasons: 1) much of the area to the south, east, and northeast is underlain by marble (Hewitt 1968); 2) the relatively flat basement surface east of the fault is typical of a marble surface; and 3) the lower seismic velocities are in the velocity range for marble (Thompson and Williams 1987, p.319).

Also of interest is the change in the magnetic anomaly profile and an apparent conductivity anomaly over the fault zone. The Bouguer gravity profile shows a steady increase east of the fault. This is not likely caused by the different Precambrian rock types on either side of the fault because their densities (assuming marble on the eastern side) are nearly the same (2.79 and 2.75 gm/cc). The increase appears to be the result of the denser, wedge-shaped layer of Shadow Lake sandstone (2.75 gm/cc) replacing the wet clay (about 2.2 gm/cc) that exists west of the fault.

Figure 55.3c confirms the presence of the Shadow Lake sandstone and of a low velocity Precambrian basement under the Concession IV road both south and north of the 5–6 sideroad. The fault in the Precambrian, identified in Figure 55.3b, evidently cuts across the Concession IV road at about 400 m. This is indicated in Figure 55.3c by the sudden drop of the Precambrian basement surface and the known outcrop hill of mafic metavolcanic rock to the north.

CONCLUSIONS

1. Exploration for fluorite deposits should be conducted along the mineralized fractures indicated in Figure 55.2 and their possible extensions. There are other possible mineralized fractures in the western part of the study area which have not yet been traced.
2. The usefulness of geophysical methods in locating faults and identifying different bedrock types in areas covered by overburden has been demonstrated.
3. The presence of mineralized fracture zones may possibly be detected by seismic bedrock profiles as well as by magnetic, conductivity, and alpha radiation surveys.
4. Geophysical surveys across extensions of the strikes of the mineralized fractures shown in Figure 55.2 would be beneficial to the fluorite study project.

ACKNOWLEDGMENTS

The assistance of the Geophysics/Geochemistry Section of the Ontario Geological Survey in conducting the gravity survey is greatly appreciated. In particular, thanks are given to Roger Barlow, Chief, and Vinod Gupta, Geophysicist, for their supervision, and to David Wadge and Peter Mark, Geophysical Assistants, who performed the field work.

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56. Project Number 87–17. Geology of the St. Ignace Island Volcanic–Plutonic Complex

R.H. Sutcliffe and A.R. Smith

Geologists, Precambrian Geology Section, Ontario Geological Survey, Toronto.

INTRODUCTION

This summary presents the preliminary results of regional mapping of Middle Proterozoic Keweenawan intrusive and volcanic rocks on St. Ignace Island (NTS 42D/12 and 42D/13) which is in the northern part of Lake Superior (Figure 56.1). The project is a continuation of petrological studies of the Keweenawan rocks in the Thunder Bay area which were initiated in 1987 (Smith and Sutcliffe 1987).

St. Ignace Island provides a cross section through an exceptionally well preserved stratovolcano and the underlying mafic to felsic magma chamber. The composite volcanic sequence, which has not been previously documented, overlies Keweenawan flood basalts. Evidence for contemporaneous mafic and felsic magmatism is well preserved in both the volcanic and intrusive rocks. The mapping and subsequent petrological studies of these rocks will refine models of magmatism, metallogenesis, and tectonism in the Keweenawan rift.

GENERAL GEOLOGY

The St. Ignace Island area was initially mapped by Tanton (1931) and subsequently mapped by Giguere (1975), at a scale of 1:63 360. The area lies within the Keweenawan or Midcontinent Rift. In the vicinity of St. Ignace Island, the rift–related rocks are part of the Osler Group and consist of a sequence of dominantly tholeiitic basalt flows with minor rhyolite and fluvial interflow sediments. Basaltic igneous activity in the Keweenawan Rift was initiated around 1109 Ma (Davis and Sutcliffe 1985) and terminated around 1086 Ma (Palmer and Davis 1987). Deep seismic reflection profiles, recorded using marine techniques, indicate that, immediately south of St. Ignace Island, the Osler Group basalts are approximately two to three kilometres thick and overlie Archean rocks of the Superior Province (Cannon *et al.*, in press).

Osler Group tholeiitic flood basalts underlie most of St. Ignace Island and are described by Giguere (1975). They consist of massive to amygdaloidal flows, with locally developed ropy tops,

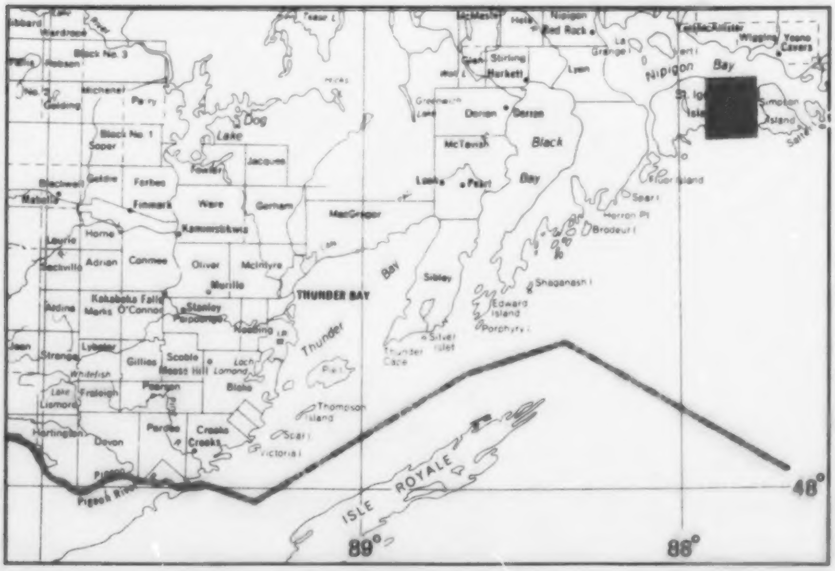

Figure 56.1. *Location map for the St. Ignace Island Volcanic–Plutonic complex study area. Scale: 1:1 584 000 or 1 inch to 25 miles.*

pahoehoe structures, and pipe amygdules. These flows are typically aphyric, with well developed ophitic textures in massive parts of the flows. Amygdules are filled with calcite, agate, zeolites, prehnite, chlorite, and quartz. Flow contacts and intercalated sedimentary rocks indicate that the regional dip of the sequence is approximately 06°S (Giguere 1975).

Rocks of the St. Ignace Island Volcanic–Plutonic Complex overlie and intrude the flood basalt sequence (Figure 56.2). The volcanic rocks of the complex consist of intercalated plagioclase-glomeroporphyritic basaltic rocks and quartz–feldspar–phyric rhyolite flows and fragmental rocks.

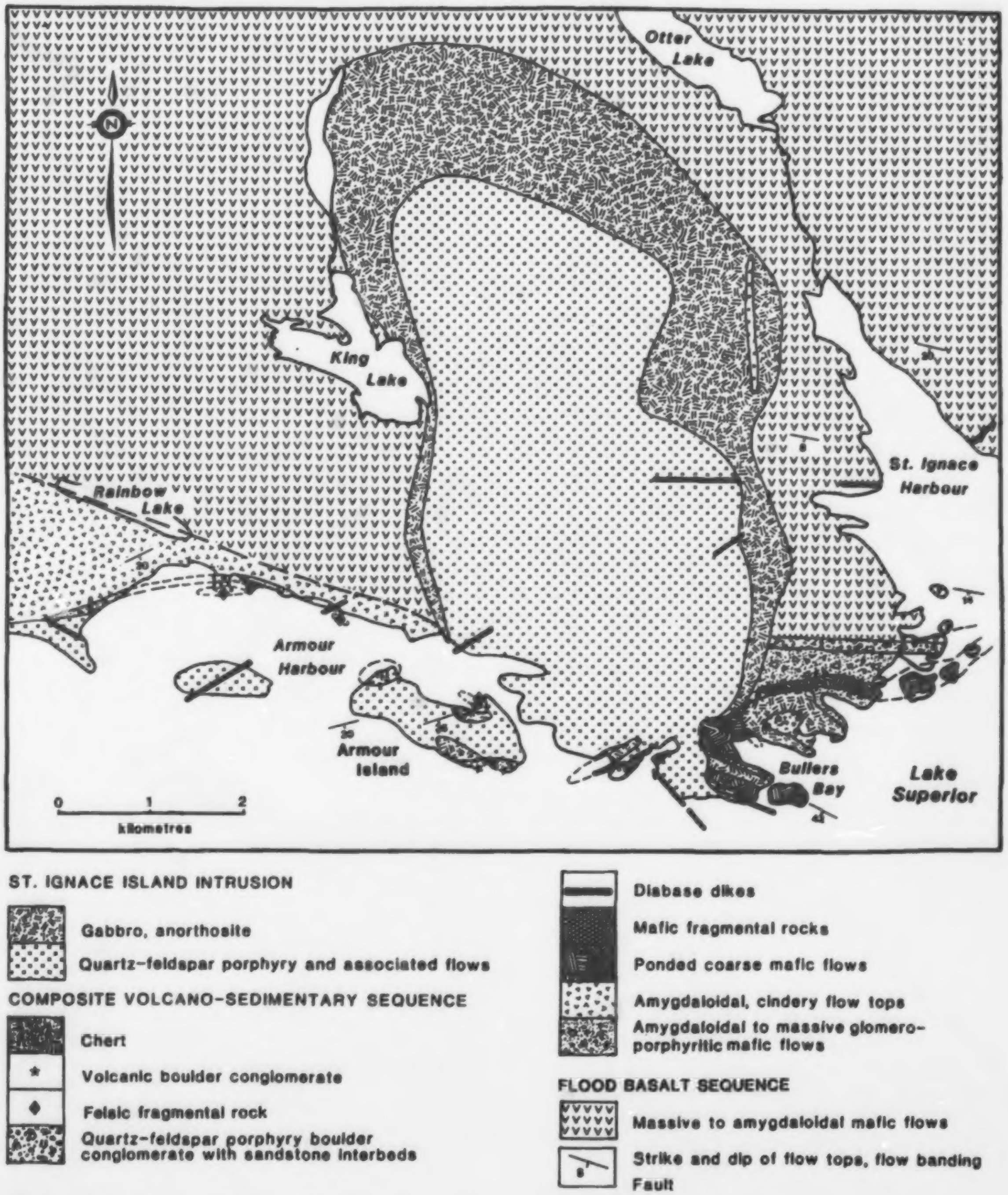
Otter Lake
King Lake
Rainbow Lake
St. Ignace Harbour
Armour Harbour
Armour Island
Bullers Bay
Lake Superior
N
0 1 2
kilometres
ST. IGNACE ISLAND INTRUSION
Gabbro, anorthosite
Quartz–feldspar porphyry and associated flows
COMPOSITE VOLCANO-SEDIMENTARY SEQUENCE
Chert
Volcanic boulder conglomerate
Felsic fragmental rock
Quartz–feldspar porphyry boulder conglomerate with sandstone interbeds
Diabase dikes
Mafic fragmental rocks
Ponded coarse mafic flows
Amygdaloidal, cindery flow tops
Amygdaloidal to massive glomeroporphyritic mafic flows
FLOOD BASALT SEQUENCE
Massive to amygdaloidal mafic flows
Strike and dip of flow tops, flow banding
Fault

Figure 56.2. *Generalized geology of the St. Ignace Island Volcanic–Plutonic Complex.*

Heterolithic and monolithic volcanic conglomerate units and associated sandstone lenses are interbedded with the flows. The intrusive rocks of the complex consist of a gabbro to anorthosite ring dike, gabbroic sills, diabase dikes, and a central quartz–feldspar porphyry stock. The volcanics are interpreted to be the extrusive equivalents of the gabbro and porphyry on the basis of the textural and mineralogical similarities. The volcanic section is exposed in the southern part of the complex due to the tilting of Keweenawan strata toward Lake Superior.

Basaltic volcanic rocks of the St. Ignace Island Complex are characterized by glomeroporphyritic and fluxion textures defined by plagioclase laths up to 1.5 cm long. The basalts occur as massive to amygdaloidal flows which commonly exhibit fragmental flow tops. Flows up to 30 m thick are present and are characterized by a gradation from very coarse, massive basalt with 0.5 to 1.5 cm grain sizes to plagioclase–phyric amygdaloidal basalt with intersertal texture.

Felsic volcanic rocks intercalated with the basalts range from massive and flow–banded rhyolite to rhyolite breccia and welded tuff. The rhyolite contains phenocryst assemblages of quartz, quartz + blocky feldspar (possibly alkali feldspar), and quartz + blocky feldspar + plagioclase laths. The felsic volcanics are characterized by numerous inclusions of plagioclase–phyric to glomeroporhyritic basalt, gabbro, and andesitic to dacitic porphyry.

Sedimentary rocks interbedded with the volcanic sequence are preserved in the vicinity of Bullers Bay and Armour Island. A monolithic volcanic conglomerate exposed on the northern side of Bullers Bay contains rounded boulders of red and grey quartz–feldspar porphyry in a clastic matrix, with cross–bedded sandstone lenses. A heterolithic volcanic conglomerate was outlined on the southern shore of Armour Island. In this unit, centimetre– to metre–sized fragments, ranging in composition from amygdaloidal and glomeroporphyritic basalt to quartz–feldspar porphyry, are supported in a sandy matrix. Rare sandstone interbeds within the volcanic flows are oxidized and range from 5 to 50 cm in thickness. Narrow chert beds from 2 to 30 cm thick occur between glomeroporphyritic flows on the southern shore of Bullers Bay.

Gabbroic rocks form the ring dike and smaller sills which are intrusive into the volcanic rocks. These intrusive rocks range in composition from gabbro to anorthosite and consist of plagioclase, clinopyroxene, olivine, and opaques. The gabbroic rocks are coarse–grained, with 0.5 to 2 cm grain sizes, and exhibit wispy modal layering and igneous lamination. At contacts with the volcanic rocks, the gabbro is chilled and contains plagioclase phenocrysts in an aphanitic matrix.

The central quartz–feldspar porphyry stock is oval in shape, with long and short axis dimensions of 7 km and 3.5 km, respectively. The stock is composed predominantly of massive, red to grey, quartz–feldspar porphyry with phenocryst assemblages identical to those of the felsic volcanic rocks. Massive grey– to buff–coloured porphyry, characterized by abundant plagioclase phenocrysts and rare quartz phenocrysts, is locally observed in the zone between the gabbro ring dike and the red quartz–feldspar porphyry core, and is interpreted to be intermediate in composition. Fine– to medium–grained plagioclase–phyric mafic inclusions are abundant in the intrusive core near the contact with the gabbro ring dike.

Ophitic and plagioclase–phyric diabase dikes intrude the gabbro, quartz–feldspar porphyry, and the volcanic rocks. These dikes range in thickness from a few decimetres to ten metres and often exhibit columnar jointing. Some of the diabase dikes form a pattern which is radial to the central felsic stock and gabbroic ring dike.

Textures in the rocks of the complex indicate that mafic and felsic magmatism were contemporaneous and that localized magma mixing occurred. Rounded, chilled mafic inclusions are common in both the felsic intrusive and volcanic rocks. These inclusions are associated with hybrid compositions in areas such as the outer part of the porphyry stock. Vesicular basaltic fragments are present in felsic welded tuff and preliminary petrographic observations indicate that plagioclase phenocrysts in felsic rocks are locally rimmed by aphanitic basalt.

ECONOMIC GEOLOGY

Exploration interest on St. Ignace Island has been primarily for copper and silver. Mineralization of interest in this area includes the presence of native copper in amygdaloidal basalt, and the occurrence of native copper and silver in calcite–quartz–chalcocite–chalcopyrite veins cutting host basalts. To date, no economically significant mineralization has been discovered in the area. Information on exploration activities reported here is from the Resident Geologist's Office, Ministry of Northern Development and Mines, Thunder Bay. Most information given here pertains to exploration in volcanic rocks on St. Ignace Island.

Early exploration work in the area was completed in 1955 by Horlac Mines Limited. Properties on the southeastern side of St. Ignace Harbour and at the northern end of Moffat Strait were investigated by diamond drilling (16 holes, 338 m) and trenching. The Moffat Strait Property was drilled again in 1964 by R.V. Oja Limited (6 holes, 469 m). Assays to 15.2 percent silver and 3.2 percent copper were reportedly obtained from drill core.

A property on the northwestern corner of St. Ignace Island was diamond drilled by Sutherland and Company in 1961 (2 holes, 455 m), and again in

1968 (1 hole, 280 m). Another property in this same area was investigated in this same year by J.L. Carroll (Prospector, N.Y.C.) with diamond drilling (8 holes, 261 m).

An extensive soil geochemical survey and a stream sediment sampling program were completed on a large part of St. Ignace Island in 1968 by Ogden Prospecting Syndicate. This work detected two minor copper anomalies on the western side of the Island. In 1970, Addicks Canadian Properties Incorporated completed ground magnetic and electromagnetic surveys on a Moffat Strait property to test for anomalies associated with known copper–silver mineralization. The survey outlined six east–trending anomalies which were interpreted to be concentrations of magnetite in basalt flows.

The occurrence of copper at the northern end of Moffat Strait was examined during the current mapping project. A carbonate–quartz vein within a deformation zone cutting basalt flows was observed to contain disseminated chalcocite, chalcopyrite, and bornite. A grab sample from a trench exposure of a 5 cm wide part of this vein returned 3070 ppm Cu.

Minor copper mineralization was encountered in intermediate intrusive rocks of the central porphyry core during the current mapping project. Fractured feldspar–porphyritic rocks exhibiting argillic alteration and disseminated chalcopyrite were encountered along the northwestern edge of the central core in close proximity to the gabbro ring dike. This type of rock represents an exploration target for porphyry–copper–type mineralization.

The gabbro and anorthositic gabbro of the ring dike are possible exploration targets for platinum group elements (PGE). Minor sulphide mineralization detected during the current mapping appears magmatic in texture, but no anomalous values of PGE were obtained on samples collected by the field party. Exploration efforts should focus on outlining and assaying similar sulphide mineralization by prospecting within the gabbroic rocks.

CONCLUDING REMARKS

The St. Ignace Island Complex has close similarities with the central complexes of the British Tertiary Volcanic Province such as the Mull and Ardnamurchan Complexes, which have been described by Bailey *et al.* (1924), Richey (1932) and Thompson (1982). Features of the St. Ignace Island Complex which are similar to the British complexes include: a rift–related tectonic setting, the presence of volcanic rocks underlain by cogenetic central intrusions, coexisting basaltic and felsic magmas with evidence of hybridization, and emplacement of magmas controlled by ring fractures.

At St. Ignace Island, planned investigations will address petrologic problems such as the characterization and origin of magma types, the nature of interaction between mafic magmas and sialic crust, and the extent of mixing between mafic and felsic magmas. The study will provide a basis for the comparison of the mineral potential of gabbroic rocks in the St. Ignace Island area with Cu–Ni–PGE–mineralized Keweenawan intrusions such as the Crystal Lake Gabbro.

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Special Studies

57. Project 88–35. Plant Spectral Signatures Versus Geochemical Values in Soil and Leaf Ash; Arnprior, Eastern Ontario

J.S. Springer[1], V.H. Singhroy[2], and F. Kenny[3]

[1]Geologist, Precambrian Geology Section, Ontario Geological Survey, Toronto.

[2]Senior Research Engineer, Ontario Centre for Remote Sensing, Ontario Ministry of Natural Resources, Toronto.

[3]Research Engineer, Ontario Centre for Remote Sensing, Ontario Ministry of Natural Resources, Toronto.

INTRODUCTION

Many studies have shown that geochemically stressed vegetation may show spectral changes in the visible and near-infrared ranges. To make this response a practical tool for mineral exploration in glaciated vegetated terrains, carefully documented case histories are needed that examine the relationship of observed spectral appearance and possible geochemical anomalies expressed in soil or vegetation.

The Arnprior site (Figure 57.1) in eastern Ontario is designed to provide a case study from the Great Lakes–St. Lawrence forest region in an area of thin glacial cover that has been culturally modified. Studies of the Kingdon Mine, Arnprior (Figure 57.2) have examined a site mineralized with Pb–Zn and two control areas. The aim has been to characterize spectral response of the vegetation; to quantify ground reflectance of tree species and its repeatability; to use two Canadian airborne sensors to defect geochemical or other stress; and to compare spectral data with analyses of leaf-ash, soil, and bedrock.

REMOTE SENSING DATA COLLECTED

The wider intent of this work is to develop a fast reconnaissance method of spotting mineralization, for example, Mississippi Valley-type lead zinc deposits in both Grenvillian and Paleozoic rocks in southeastern Ontario. Here, small Pb–Zn–Sr–Ba–Fl deposits in the past have been worked commercially and larger economic occurrences might remain to be found.

Geobotanical signatures are only one tool applicable in exploration. Geological constraints and a broad geological rationale on which geobotanical exploration methods are based have been outlined by Springer *et al.* (1987).

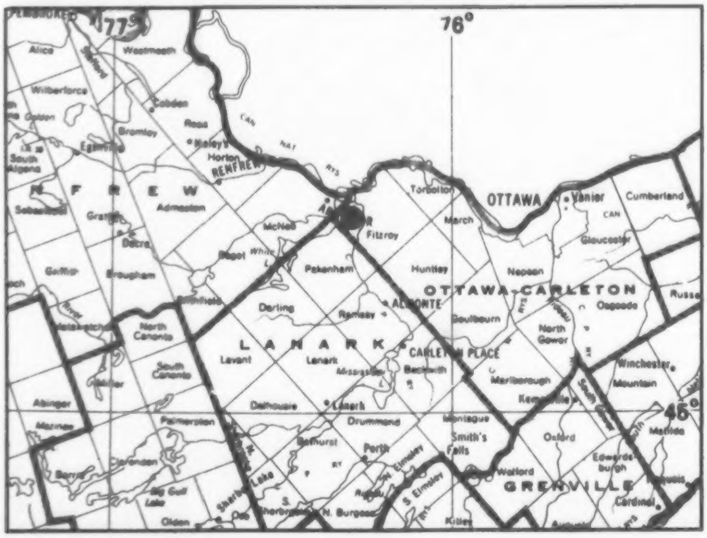
77°
76°
45°
Alice
Westmeath
Wilberforce
Cobden
Ross
Bromley
Horton
RENFREW
Admaston
Grattan
McNab
Fitzroy
Torbolton
OTTAWA
Vanier
Cumberland
March
Gloucester
Huntley
Nepean
Pakenham
Brougham
Darling
Ramsay
ALMONTE
OTTAWA–CARLETON
Goulbourn
Osgoode
North Gower
LANARK
Levant
Lanark
CARLETON PLACE
Beckwith
Marlborough
Winchester
Mountain
Abinger
Dalhousie
Drummond
Montague
Smith's Falls
Palmerston
Bathurst
Perth
Oxford
Matilda
Edwardsburgh
Wolford
GRENVILLE
Cardinal
Big Gull Lake
Oldon
N. Burgess
S. Elmsley

Figure 57.1. *Location map for the Arnprior site in Eastern Ontario. Scale: 1:1 584 000 or 1 inch to 25 miles.*

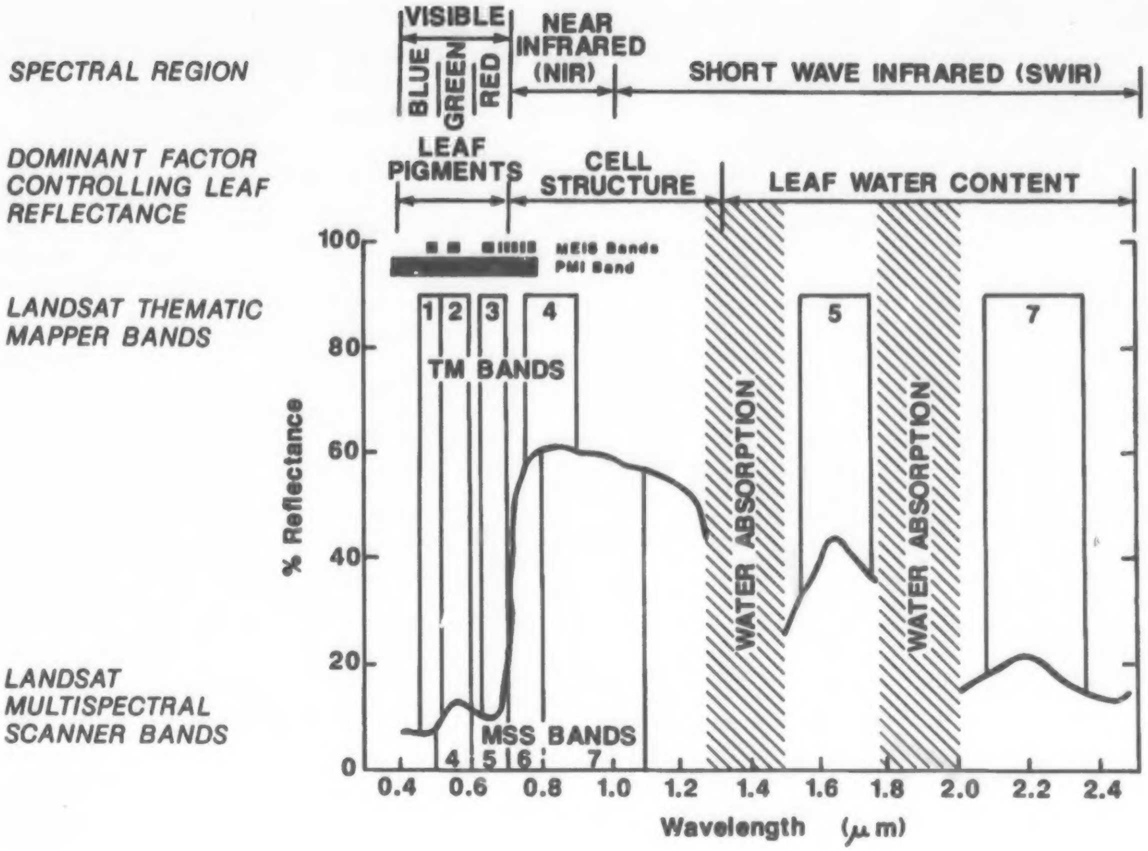

Figure 57.2. *Graph of Percentage Reflectance Versus Wavelength (μm).*

Data collected simultaneously on an airborne mission in early September 1985 include:

1. colour infrared–photography at a scale of 1:15 000, for identifying vegetation types and selecting sites for field sampling, and
2. narrow band MEIS II (Multispectral Electro–optical imaging Scanner) data with a spatial resolution of 4.2 m, at nanometer wavelengths of 680, 713, 753, and 798, using the geobotany filter set.

The flight was scheduled for late August in the hope that stress, induced by drought or early wintering, would enhance the spectral shift at the edge between red and blue wave lengths.

The Arnprior site was flown in July 1987, using the Programmable Multispectral Imager (formerly the Fluorescence Line Imager), developed by Moniteq Limited, to yield a comparative data set. The flight was scheduled for earlier in the year than the previous flight to evaluate the effects of senescence on the reflectance values.

The wavelength of the MEIS filters relative to the wavelengths at which physiologically important plant functions cause reflectance changes is shown in Figure 57.2. The broader range scanned by the FLI (PMI) sensor is also shown.

FIELD SAMPLING

Data sets of spectra measured at ground level for five major tree species, namely trembling aspen, white birch, red oak, bur oak and maple, now exist for the years 1985 to 1988, together with other observations for white cedar, juniper, hemlock, and ash. The leaves are collected on site from the crown and upper surface of the trees (areas that would be visible from the air), sealed in plastic bags, and cooled until their spectra can be read under standard, controlled indoor conditions. This must be done within four hours to prevent artifacts due to wilting and chlorophyll destruction. Ground observations of spectra have been obtained from one mineralized and two control sites.

At these same sites, 50 by 50 m grids have provided a basis for sampling soil and the first year growth of tree species. The leaves are stripped and placed in paper bags for later oven drying, preliminary steps to ashing, dissolution, and analysis by qualitative inductively coupled plasma spectrometry. Soil samples undergo the same analysis.

RESULTS

SOIL AND VEGETATION DATA

So far, the analytical data show a distinct anomaly for base metals at the mineralized site. Figure 57.3 takes zinc as an example, where the average background value in the "B" soil horizon is less than 200 ppm and in the mineralized soil values averages over 3000 ppm.

It appears that the vegetation, species by species, achieves characteristic metal levels in the leaf ash, and that even high values of metal content in the surrounding soil do not increase that uptake by more than twofold. The typical level appears to vary, species by species, to a much greater extent; thus, maples at the unmineralized site average 40 ppm, whereas birch averages about ten times that value (440 ppm). In each case at the mineralized site, the leaf ash enrichment is only about twofold, although the soil enrichment is nearly 20 times.

GROUND SPECTRAL DATA

Characteristic displacements of the spectral curve were repeatedly found in the foliage analyzed. Figure 57.4 illustrates data from 20 trembling aspen samples from the mineralized site. In the visible range, increased reflectance and yellowing (chlorosis) of the leaves appear, indicative of chlorophyll destruction. At the red edge, the curve is shifted toward blue wavelengths, suggesting damage to cell wall structure. At the shoulders of the curve, in the 680 nm range, there is increased reflectance which appears to denote water loss and wilting.

REMOTELY SENSED SPECTRAL DATA

The images obtained by the MEIS II and the PM 1 sensors were enhanced using the wavelengths found in the ground data to be most sensitive to change. When this is done, broad patterns of stressed vegetation become apparent. This revealed that anomalous growth occurs in a wide halo around the mine site, along power lines that cross the area, and along access roads to the mine.

The PM 1 image in particular, analyzed using the 680 nm wave band which marks abundant chlorophyll in a normally photosynthesizing plant, showed broad swathes of lowered chlorophyll production along cultural features. This revealed that the 'background' control area was itself an area of depressed growth. As a consequence, a new control site was selected and a fresh suite of soil, vegetation, and ground spectral data have been collected.

CONCLUSIONS

1. Analysis of leaf ash is probably not a sensitive test of anomalous soil metal contents, because the physiological activity of the vegetation buffers the metal uptake.
2. Spectral reflectance in the visible and near infrared ranges shows consistent and predictable variation at the mineralized site. The differences appear at characteristic positions on the reflectance curve and perhaps correspond to physiological changes such as chlorophyll destruction, damage to cell walls, and dehydration that lead to wilting.

Ground measurements, at this stage, are vital to successful interpretation of remotely sensed spectral observation.

3. Both MEIS and PMI imaging are sensitive to stressed vegetation. The PMI data, in particular at the 680 nm wavelength, detect depressed chlorophyll production with good sensitivity.
4. In this study, at present, the distinction between stress related to cultural activities and stress related to mineralization cannot be made. In this study, the effects of cultural activities related to the mine overprint the site-specific signature of the vein mineralization itself. More work is needed to permit screening out the cultural overprint.

	BACKGROUND (ppm)	MINERALIZED (ppm)	
SOIL "B"	170	3300	
VEGETATION			ENRICHMENT
Birch	440	800	1.8x
T.Aspen	500	760	1.5x
Maple	40	70	1.9x
Bur Oak	30	60	1.9x

Figure 57.3. *Zinc values, Arnprior (Kingdon Mine).*

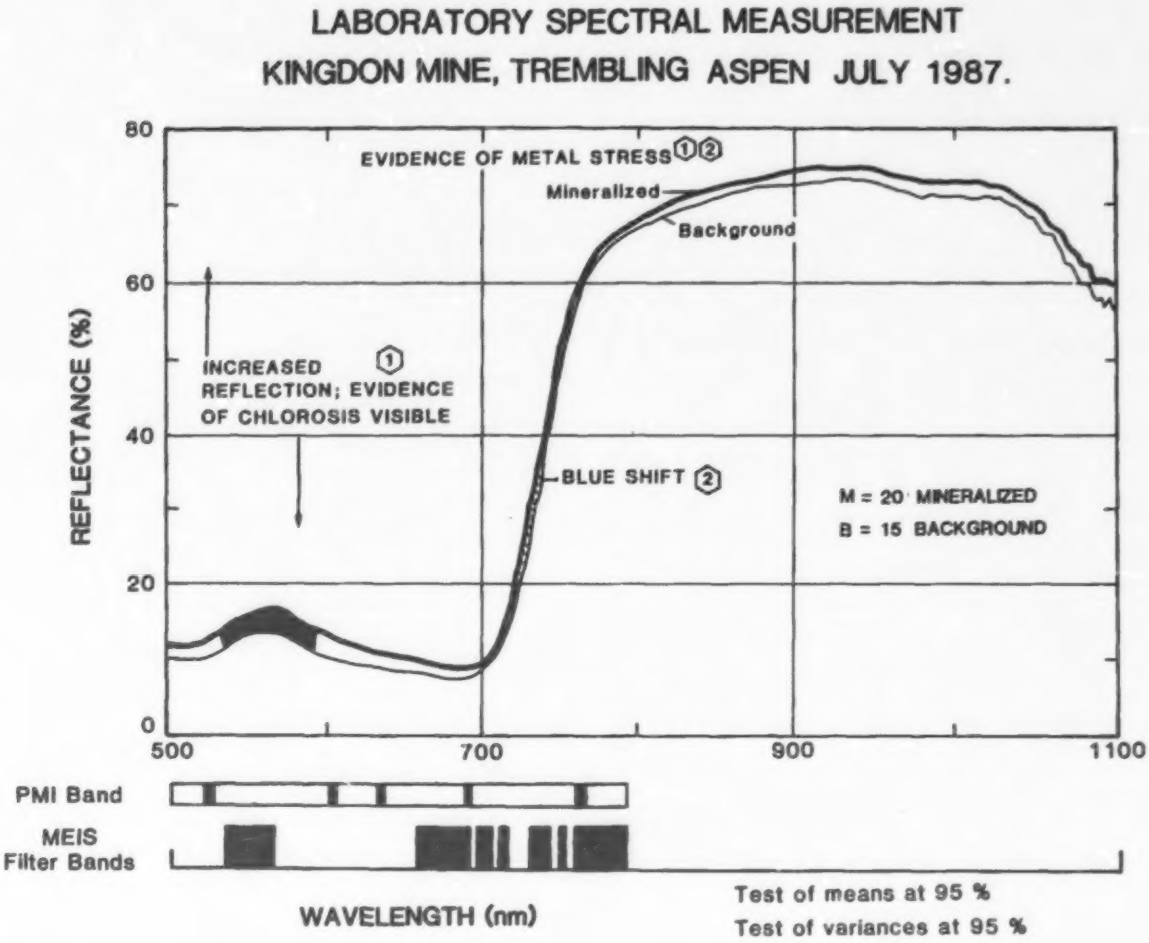

Figure 57.4. *Laboratory Spectral Measurement, Kingdon Mine, July 1987.*

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58. Project Number 88–32. Field Implementation of a Developmental Computer–Based Digital Mapping and Data Storage System

B. Brodaric[1] **and J.A. Fyon**[2]

[1]Systems Officer, Precambrian Geology Section, Ontario Geological Survey, Toronto.

[2]Geologist, Precambrian Geology Section, Ontario Geological Survey, Toronto.

INTRODUCTION

The recent development of powerful portable microcomputers and complementary data base and graphics software presents an opportunity to shift from traditional manual manipulation of geological field data. The Precambrian Geology Section of the Ontario Geological Survey (OGS) has embarked upon a developmental program to incorporate this technology into field programs. The program began this summer with field testing of an interactive computer–based field note system, having integrated cartographic and relational data base capability. A "386" AutoCAD–dBASE[1] package was deployed in four Precambrian Section field crews. While the shift to digital map production and maintenance from traditional cartographic methods is labour–economic, and possesses great potential for reducing manual drafting loads, it is in the area of analysis where possibly the greatest gains are to be realized. Available to the geologist is the technological capability to analyze large amounts of diverse quantitative and qualitative data, and to produce a spectrum of geological maps ranging from conventional comprehensive maps (e.g. standard Preliminary Series maps) to attribute–specific maps (e.g. distribution of sheared rhyolite flows bearing S3 foliation). Having this capability available in the field facilitates data entry, because of available manpower and time, when the data are most familiar to the geologist, and contributes to the identification of significant relationships. More comprehensive data analysis can follow in the office environment, as more and varied data become available (e.g. petrographical, geochemical, geophysical data).

The archival loss of geological data is minimized and future data access should be enhanced because the data are recorded in a relational data base, as opposed to field notebooks. Such data storage and the capability to select a spectrum of data for "instantaneous" map output should significantly reduce the time required for a new geologist to become familiar with an area, and should facilitate comparison between adjacent areas. The digital approach will ultimately enhance the transfer of information between organizations, both within and outside the Ontario Geological Survey.

DESIGN PHILOSOPHY

The hardware and software components of the system were selected, linked, and modified to satisfy certain philosophical design criteria. As a primary objective, the error rate associated with data entry had to be minimized, insofar as the value of any data base rapidly diminishes as data errors are introduced. Two types of error were anticipated: 1) typographical, and 2) incorrect data location and assignment. Type "2" errors are virtually eliminated and type "1" errors are minimized when data are input into the data base interactively with a graphics display. The geologist obtains an instantaneous visual presentation of the data value, location, and assignment in terms of quantity and symbology (e.g. foliation orientation, dip value, and station location).

As a second principal requirement, the system had to be easily adaptable to a spectrum of geological projects of varying objectives and geological expertise, and hence, a multifile relational data base approach was adopted. In addition, it was desirable to provide a package for which data entry was not onerous and which did not require a sophisticated level of computer and software familiarity (i.e. user friendly).

TECHNOLOGICAL DESIGN

Portable "80386" processor–based IBM compatible microcomputers with 2 Mb of memory, a 40 Mb hard disk, a high resolution screen, and a digitizing pad were employed. The high resolution screen, larger memory and faster processor speeds were required for adequate graphics and database processing, while maintaining the ability to integrate with the in–house computer network. An EPSON FX–86e dot matrix printer allowed working maps to be printed. The units functioned favourably in varied field conditions, including operation from small generators in remote locations.

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[1] AutoCAD and dBASE are registered trademarks of Autodesk, Incorporated and Ashton–Tate Company, respectively.

SOFTWARE SELECTION

Construction of the map and data base was carried out through interactive data input within a popular cartographic software package (AutoCAD) and a relational database (dBASE). Apart from its strong cartographic abilities, customization features, and wide market popularity, an initial attraction to this system over more standard Geographic Information Systems (GIS) was its adaptability to field–suitable technology. Extensive customization of AutoCAD was necessary to implement the structured data entry format. This was accomplished using AutoLISP[2], a high level programming language within AutoCAD, which interacted with several dedicated dBASE batch programs required to manipulate the data base. dBASE was selected as the relational data base because of its adequacy of use, its wide industry acceptance, and its familiarity within the OGS.

MODULAR DATA BASE DESIGN

The data base design is modular. This requires that project objectives be logically broken into several geological divisions, each of which has an equivalent related data base file. Conceptually, a typical mapping project will encounter lithological, structural, alteration, and commodity problems. This conceptual structure is then translated into a relational data base consisting of lithological, structural, alteration, and commodity modules. These are defined by the project geologist to fit his expertise and project initiatives prior to the onset of mapping. The division of geological data, while intended primarily to economically structure the data base, has the added benefit of organizing the nature of the geological problem, and contributes to the processes of problem formulation and analysis.

For data entry, the geologist is presented with a series of prompts, determined by the module selected. As the system was designed for flexibility in dealing with diverse geological problems, geologists completely tailor the input prompts, and, therefore, the information to be stored in the data base and displayed on the map. This structure can be modified at any time, allowing for the deletion of unwanted items and the addition of pertinent prompts. Changing the input prompts results in appropriate modification to the data base format, removing or adding the required space and data. This maintenance is carried out by an easy–to–use auxiliary program. Once the project needs are established by the geologist and translated both into AutoCAD prompts and dBASE data bases, the actual data entry in AutoCAD is routine, requiring minimal computer knowledge and experience.

Users can recall data from the data base and alter it through the interactive input mode, as well as perform global changes to the map and data base. This is particularly useful when the field legend must be changed or condensed. In these aspects, the system generally resembles a typical GIS. Although the AutoCAD/dBASE amalgamation is somewhat limited in typical GIS spatial analysis capabilities, AutoCAD is unsurpassed in its cartographic scope and portability, while adhering to the spatially referenced data base construction that broadly defines a GIS.

Although the input of data into the modular data base is not dependent on the style in which data is recorded in the field, formatted notes were found to be inherently more efficient. Another important feature of the present cartographic input system is its adaptability to other relational data bases, although the conversion of existing data bases to this modular system does require some custom programming.

FIELD PROJECT SELECTION

Four field parties were selected to test this package. The projects with which these parties were associated represent in total a spectrum of geological objectives and geological specialization. Mapping took place on reconnaissance (1:50 000), township (1:15 840), and detailed (1:8000 to 1:1000) scales. The emphasis of the projects included a reconnaissance sedimentological study and lithological, structural, alteration, and commodity studies at township and detailed scales.

DIGITAL BASE MAPS

Geographical base maps were digitized by hand, in AutoCAD, to allow a degree of selectivity in the type and detail of information recorded. A trend to using existing digital maps, or maps generated by optical scanning techniques is foreseen for the future.

DAILY ENTRY OF DATA

Following each traverse, an air photo mylar overlay, marked with the daily traverse and outcrop patterns, is fixed to the digitizing board and coordinated to the digital base map. Each outcrop is traced (digitized) from the mylar overlay. The user then selects an appropriate module (e.g. lithology module), relevant to that outcrop. Appropriate data are entered in response to a sequence of prompts, which add geological symbols to the digitized base map. For displayed data, the geologist is required to select the appropriate symbol (e.g. oldest inclined foliation), identify the symbol's position on the map, and enter any other required qualifications (e.g. strike and dip of a planar feature). This sequence is repeated iteratively for each outcrop, and the data are periodically exported to the relational data base. Both prompts and map appear on the computer screen simultaneously, yielding a traditional cartographic feel to the map development, as well as enabling users to monitor and visually confirm data entry at input time.

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[2] AutoLISP is a registered trademark of Autodesk, Incorporated.

The time required to log the daily collection of data was variable, depending on the complexity of the outcrop; however, data entry time averaged two to four times that required to plot the same data on a conventional mylar working map. It is anticipated that this time investment in the field will be recouped in the office environment, where data analysis will continue and drafting requirements will be reduced.

A variety of field note styles were adopted by the parties, ranging from free format to structured code. In general, a longer time was required to input data when the basic field data were collected in a less structured manner.

SUMMARY

The field testing demonstrated that the hardware and software configurations operated under rigorous conditions. The developed system allows for "instantaneous" map generation and allows for data and map modification. Further testing and development will continue over the winter and into the next field season.

59. Project Number 88–31. Petrographic Characteristics of Archean Granitoid Rocks

J.A. Fyon and K.J. Wheatley

Geologists, Precambrian Geology Section, Ontario Geological Survey, Toronto.

INTRODUCTION

The intent of this project is to develop a basic petrographic data base describing the mineralogical and textural characteristics of Archean granitoid rocks and to assess the degree to which these data constrain the granitoid crystallization history, including the evolution of magmatic fluids. When combined with geochemical data, this analysis will contribute to our understanding of Archean granitoid petrogenesis, and attendant thermal and tectonic conditions. Additional constraints will be provided for some proposed Archean metallogenic models which appeal to magmatic processes (e.g. genesis of gold mineralization). Initially, three granitoid intrusions in the Uchi Greenstone Belt and one from the Temagami Greenstone Belt have been examined to evaluate the approach.

UCHI LAKE GREENSTONE BELT

TROUT LAKE BATHOLITH

The Trout Lake Batholith is a composite tonalite and trondhjemite external batholith, consisting of migmatitic trondhjemite gneiss, banded diorite–granodiorite gneiss, and trondhjemite–diorite–granodiorite phases (Donaldson 1963, Noble *et al.* 1984, 1985, 1988).

Oligoclase–andesine plagioclase occurs as euhedral to subhedral crystals up to 5 mm in length and both albite and carlsbad twins are developed. All crystals show normal compositional zonation. Most plagioclase is replaced to some extent by white mica and epidote; generally alteration of the core is more extensive than the rim. Poikilitic microcline is present in virtually all samples and contains inclusions of plagioclase. Hornblende is present in trace amounts, but is absent from most samples. Biotite occurs in all samples and has been replaced variably by chlorite and white mica. Euhedral to subhedral epidote, up to 1 mm in length, occurs in virtually every sample, where it is associated intimately with biotite. Some of these euhedral to subhedral epidote crystals are commonly twinned.

MAIN PRIZE LAKE BATHOLITH

A pink, microcline megacrystic granite–granodiorite (Main Prize Lake Batholith, Beakhouse and McNeil 1986) intrudes the northwestern part of the greenstone belt (Greig 1927). The most distinctive mesoscopic feature of this intrusion are coarse (1 to 5 cm), poikilitic microcline feldspar. These microcline crystals enclose and embay quartz, biotite, and hornblende. Compositionally zoned oligoclase plagioclase is intergrown with the megacrystic microcline feldspar. Microcline also occurs in a second habit, as distinctly smaller crystals (<1 mm) associated with the other matrix silicate minerals. Subhedral to anhedral hornblende occurs in lesser amounts and biotite occurs as rare inclusions within the plagioclase. Euhedral to subhedral sphene occurs in minor amounts, often as an inclusion in biotite.

SWAIN LAKE STOCK

This is a poorly exposed, feldspar–rich internal trondhjemitic stock (Furse 1933). Samples examined consist almost entirely of plagioclase, with minor amounts of hornblende and rare quartz. Euhedral to subhedral plagioclase feldspar constitutes about 65% of the rock. This feldspar is badly altered and has been replaced by white mica and epidote. In general, the cores of grains are more altered than the rims, suggesting that the cores were originally more calcic than the rims. Relic twinning and compositional zoning are still discernible, although no crystal was fresh enough to provide a petrographic compositional estimate. Hornblende occurs as subhedral phenocrysts, many of which have been replaced by chlorite and epidote. No biotite was observed.

TEMAGAMI GREENSTONE BELT

STRATHY–CHAMBERS BATHOLITH

This is a tonalite–trondhjemite intrusion, which contains minor amounts of pegmatite and aplite. Plagioclase (albite to oligoclase) occurs as subhedral to euhedral laths, primarily in crystal aggregates. Most grains exhibit albite twinning; multiple twinning is less common. Normal compositional zoning is present in most samples. Plagioclase generally contains inclusions of apatite, zircon, opaque minerals, quartz, and femic minerals. Perthitic, poikilitic, alkali feldspar encloses and sometimes embays inclusions of plagioclase, quartz, femic minerals, and euhedral opaque minerals. Microcline twinning is variably developed and generally patchy. The sodium feldspar component of patch perthite sometimes exhibits albite twinning. A second, less common habit of the alkali feldspar is finer grained, blocky crystals (0.5 mm) which occur as part of the interlocking network of matrix grains. Quartz is generally anhedral, equant, and polycrystalline. It is interstitial to, contains inclusions of, and is included in the other constituent mineral grains. Chlorite is the dominant femic mineral and is invariably associated with epidote. It is uniformly distributed throughout the rock in clusters of stout flakes. Hornblende is rare, but is present in some samples as subhedral to euhedral, tabular to prismatic crystals, up to 3 mm in length. It contains inclusions of quartz, plagioclase, apatite, zircon, and opaque minerals. Biotite occurs as tight clusters of stout flakes and contains inclusions of epidote, zircon, and quartz. Epidote occurs as anhedral to subhedral, granular to sub–prismatic grains. Both chlorite and epidote have a second occurrence as hydrothermal alteration products of plagioclase. Sphene occurs as accessory subhedral grains, intergrown with the femic minerals. It also occurs as a secondary alteration product of plagioclase and as granular to sub–prismatic crystals, partially rimming epidote and iron–oxides. In some samples, there are a few occurrences of euhedral sphene as inclusions in plagioclase, suggesting a third, earlier generation of sphene. Euhedral zircon and apatite are common accessory minerals, which occur as inclusions in all the other mineral grains.

The degree of alteration of plagioclase varies from minor to extreme. Most grains are highly altered to sericite, and to a lesser degree, to epidote, clinozoisite, chlorite, sphene, and calcite. Alkali feldspar is less altered than plagioclase. Hornblende is variably replaced by chlorite, epidote, calcite, and sphene. Biotite is replaced by chlorite, epidote, clinozoisite, calcite, and sericite. Calcite also occurs as a secondary alteration product and fills randomly oriented, narrow veinlets that cut the rock.

MAGMATIC EPIDOTE

Magmatic epidote has been described in Phanerozoic tonalite and granodiorite plutons, where it displays textural habits suggesting that it precipitated later in the magmatic paragenesis (Zen and Hammarstrom 1984). The spatial and textural relationships between magmatic epidote and biotite in the Phanerozoic intrusions (Zen and Hammarstrom 1984) are very similar to those observed in the Trout Lake and Strathy–Chambers Batholith samples, although no intergrowth with plagioclase or inclusions of hornblende within epidote have been observed in these Archean samples. Experimental data show that biotite and epidote have overlapping crystallization fields, but such is not the case for hornblende and epidote (Naney 1983) and hornblende usually reacts out during epidote crystallization. Thus, the relatively ubiquitous epidote of possible magmatic origin in the Trout Lake and Strathy–Chambers Batholiths is consistent with the rarity of hornblende.

IMPLICATIONS FOR GRANITOID PETROLOGY

Because of the few number of samples examined to date, implications of these observations regarding the magmatic crystallization history and related magmatic fluid evolution of the intrusions are regarded as preliminary. In addition, only one aspect of the crystallization history is examined in the context of the mineralogy and textures—the contribution of water to the total volatile pressure ambient during crystallization.

HYPERSOLVUS INTRUSIONS

Virtually all samples of the Trout Lake, Main Prize, and Strathy–Chambers Batholiths contain two feldspars: oligoclase and microcline. The sodium feldspar (albite) component of the alkali feldspar occurs primarily as an exsolution product in microcline. These feldspar relationships are consistent with those of hypersolvus intrusions, which crystallized alkali feldspar at a temperature above the solvus in the binary system $NaAlSi_3O_8$–$KAlSi_3O_8$. The temperature was therefore as high as 660°C, and perhaps as high as 900°C, and the ambient water pressure during crystallization may have been less than 5 Kb (Tuttle and Bowen 1958).

In the Swain Lake Stock, plagioclase is the dominant feldspar and only one grain of orthoclase (tentatively identified) was observed. Based on limited data, it is cautiously concluded that the Swain Lake Stock is also an hypersolvus intrusion, which underwent relatively rapid cooling to inhibit the inversion of orthoclase to microcline.

SIGNIFICANCE OF PERTHITIC MICROCLINE

Tuttle and Bowen (1958) suggested that perthitic exsolution texture unmixes very rapidly in the presence of an aqueous phase. Therefore, the preservation of perthitic alkali feldspar in the Trout Lake, Main Prize Lake, and Strathy–Chambers Batholiths may indicate rapid cooling of the intrusions and/or cooling under volatile–reduced (low activity of H_2O) conditions, perhaps below 5 Kb (equivalent water pressure). However, the grain size of the magmatic quartz, plagioclase, and microcline (0.25 to 5 cm) in these intrusions is not consistent with rapid crystallization. Thus, it is concluded that the Trout Lake, Main Prize Lake, and Strathy–Chambers Batholiths are hypersolvus intrusions which cooled under low water pressure (<5 Kb?).

MAGMATIC EPIDOTE

Epidote of possible magmatic origin is commonly associated with biotite in the Trout Lake Batholith and chlorite in the Strathy–Chambers Batholith. Experimental data show that crystallization of magmatic epidote in rocks of this bulk composition takes place at elevated confining pressure (>5 Kb, Naney 1983). This has been confirmed by the application of the aluminum hornblende geobarometer (Hammarstrom and Zen 1986, Hollister *et al.* 1987), where only those plutons which crystallized at confining pressures greater than 5 Kb contained magmatic epidote.

Note that the inferred total pressure estimate for Trout Lake and Strathy–Chambers Batholith crystallization, based on the presence of "magmatic" epidote, is higher than the water pressure estimate implied by the alkali feldspar petrography. This contradictory pressure estimate could indicate that: 1) the epidote observed in the Trout Lake and Strathy–Chambers Batholiths is not magmatic, or 2) the magmas did in fact evolve under higher pressure conditions, but that the component of total pressure contributed by water was less than about 5 Kb. This latter possibility would allow the preservation of the perthitic texture, because water activity was low. If a_{H_2O} was low, then to satisfy the high pressure requirement implied by the presence of magmatic epidote, the volatile phase may have been multicomponent. If CO_2 were present, the total volatile pressure could have exceeded 5 Kb, while water pressure could have remained less than 5 Kb.

CONCLUSIONS

The principal results of this preliminary petrographic study are:

1) The feldspar relationships are consistent with those typical of hypersolvus intrusions, which crystallized under water pressures less than 5 Kb.

2) The preservation of the perthitic exsolution in microcline is consistent with alkali feldspar crystallization under volatile (aqueous) reduced conditions (<5 Kb).

3) Epidote of possible magmatic origin occurs in the Trout Lake and Strathy–Chambers Batholiths. These bodies may have crystallized under total pressures greater than 5 Kb, but in the presence of a "mixed" water–CO_2 fluid phase.

While simplistic, these tentative conclusions demonstrate that additional insight to the crystallization history and magmatic fluid evolution of an intrusive body is provided by petrographic data. The short term objective of this project remains the addition of data from more diverse intrusions and a more complete characterization of intrusive bodies from the Uchi and Temagami Greenstone Belts. Realistically, interpretation of the observations must be made in terms of complex fluid evolution, including the exsolution and release of CO_2–rich vapour aliquots, early in the crystallization history.

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60. Project Number 85–20. Geochemical Classification of Archean Volcanic Rocks

R.M. Easton[1], E.C. Grunsky[1,2], P.C. Thurston[1], L.S. Jensen[1], and J.M. Howe[3]

[1]Geologist, Precambrian Geology Section, Ontario Geological Survey, Toronto.

[2]Now at CSIRO, Perth, Western Australia.

[3]Geological Assistant, Precambrian Geology Section, Ontario Geological Survey, Toronto.

INTRODUCTION

Investigation of methods of geochemical classification of volcanic rocks has continued since the establishment of a working group in 1985, composed of R.M. Easton (chair), E.C. Grunsky, L.S. Jensen, and P.C. Thurston to study various means of classifying Archean volcanic rocks. J.M. Howe has assisted the working group with data processing, data compilation, and preparation of the komatiite data base (Howe *et al.* 1987).

The establishment of the working group was based on the need to classify Archean volcanic rocks adequately, as well as to distinguish the extent of chemical alteration of Archean volcanic rocks. The ability to properly classify volcanic rocks as well as to determine the nature of any associated alteration has significant implications for mineral exploration. Grunsky *et al.* (1986) discussed the attributes of a useful Archean volcanic rock classification scheme and briefly reviewed several commonly used geochemical classification schemes.

The working group's approach involves the assembly of a data base of major and trace element chemical data from Ontario Archean volcanic rocks, as well as analytical data from selected Archean and modern volcanic suites for comparative and testing purposes. By using a variety of techniques of multivariate data analysis and statistics (outlined in Grunsky *et al.* 1986, 1987), the authors hope to determine the essential chemical components that characterize the petrogenetically related chemical variation within and between a variety of volcanic suites. Currently recognized volcanic suites within the Archean are: (1) ultramafic–komatiitic, (2) tholeiitic, (3) calc–alkalic, and (4) alkalic.

By using multivariate data analysis and statistics, all elements (as opposed to only three or four in standard ternary plots) can be used to determine the petrogenetic chemical variation of the suites, to distinguish rocks that have been altered, and to characterize the type of alteration (e.g. hydration, potassium metasomatism, silicification, carbonatization). Once the working group has determined which elements are most effective in distinguishing between rock suites, petrogenetic processes and alteration, then this knowledge can be used to construct a variety of binary and ternary discrimination plots that will be effective in illustrating different types of geochemical behavoir in Archean volcanic rocks.

The datasets in each major magmatic association are tested by several techniques of multivariate data analysis and statistics. Grunsky *et al.* (1986, 1987) summarized the various techniques used. Correspondence analysis (Davis 1986) and dynamic cluster analysis (Lefebvre and David 1977) are the two main techniques used by the group so far. The working group favours correspondence analysis because it allows for the simultaneous projection of both the sample and variable factor scores in the same factor space (Figure 60.1). Tests of classification schemes and diagrams are made by comparison of datasets of relatively unaltered, usually modern rocks representing each volcanic suite.

Compilation and classification of the komatiite suite was begun in 1985 (Grunsky *et al.* 1986, 1987)

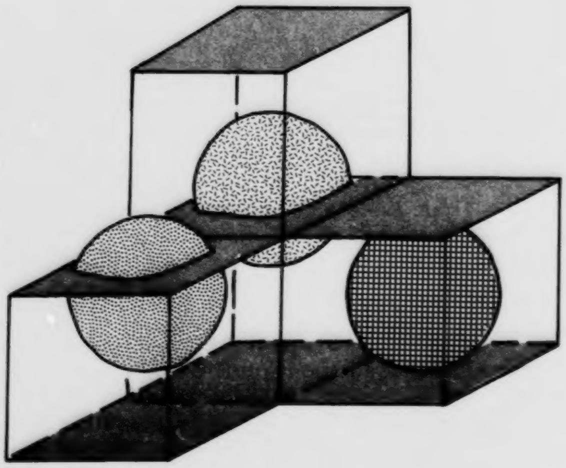

Figure 60.1. *This is a 3-D representation of the factor score diagrams shown in Figures 60.2, 60.3, and 60.4. The various rock suites are represented by clouds of data points, which appear as 2-D clusters on the factor score diagrams. The relationship of the clusters varies depending on the plane the data points are projected on to.*

and the komatiite data base was published in 1987 (Howe *et al.* 1987). Compilation of geochemical data of the tholeiitic, calc–alkalic, and alkalic suites and their classification were carried out in the past year, and some preliminary results are described below.

CLASSIFICATION OF VOLCANIC ROCKS

Analysis of the suites outlined below to date is based solely on major elements; Si, Al, FeO(t), Mg, Ca, Na, K, Ti, Mn, P, and total volatiles being those components considered. Total iron is used because not all analyses include both ferrous and feric iron. Work began initially using the major elements because: (1) most analyses of rocks in the PETROCH data base of the Ontario Geological Survey have complete major element analyses. Trace element analyses are not available for many older analyses, and where present, no consistent set of trace elements is used; (2) there are many existing discrimination plots based on the major elements; (3) volatiles and the alkalis provide an indication of alteration; and (4) the group's work with the komatiite suite using the major element was fruitful. Except for the komatiite data base, the nature of which is described in Howe *et al.* (1987), samples were selected from the PETROCH data base of the Ontario Geological Survey. Selection criteria for the komatiites are given in Grunsky *et al.* (1987). Similar broad criteria were used in selecting the tholeiite, and calc–alkalic rocks from the PETROCH data base. Samples in PETROCH classed in the field as tholeiitic, volcanic, and having less than 10% MgO, and between 48% and 65% SiO_2 were used to construct the tholeiite data base. Samples classed in the field as calc–alkalic, volcanic, and greater than 50% SiO_2, greater than 15% Al_2O_3, less than 10% FeO(t), less than 6% MgO, less than 6% K_2O, and between 2% and 7%. Na_2O were included in the calc–alkalic data base. The field designation, commonly based on stratigraphy, was used in the selection as a means to broadly separate the two suites; this approach was preferred to using strictly chemical criteria to separate the suites. In the case of the alkalic rocks, the group presently has selected only well documented samples in the PETROCH data base with clear geological relationships. This approach has been taken because no diagnostic chemical criteria exist at present for classifying these rocks.

Initially, broad criteria have been used in selecting samples in order to determine if we can indeed discriminate between altered and unaltered samples, and between the different suites. If this method is valid, then we should be able to recognize misclassified or extremely altered samples.

THOLEIITE SUITE

Last year (Grunsky *et al.* 1987) the working group reported on a preliminary analysis of 100 tholeiites from the Kenojevis Group, Abitibi Greenstone Belt. During the past year, the group has added to the Archean tholeiite data base. It now contains 2536 samples, all from within Ontario. Although additional analyses are available, it has been found that this is an appropriate number for statistical data processing based on the knowledge that these 2536 samples have well defined geological attributes and reliable geochemistry.

Results for correspondence analyses of the 2536 tholeiite suite rocks are tabulated in Table 60.1, and illustrated in Figures 60.2a, 60.2b, and 60.2c. The first factor accounts for a third of the variation (36.0%). The first factor is dominated by the variation of K (43.2%), Ca (23.2%), volatiles (H_2O and CO_2) (11.4%), and Mg and Fe (16.6%). The second factor (17.3% of the total variation) is dominated by the volatiles (48.2%) and K (37.1%). Ca, K, and Na are significant in both Factors 1 and 2 and, therefore, it is not possible to clearly separate the effects of plagioclase fraction versus alteration on the Factor 1 versus Factor 2 plot (Figure 60.2a). Normally, one would expect that the primary igneous variation (Ca, Fe, Mg, Na, K) would be accounted for within the first factor. However, the variation of Mg, Fe, and Ca is significantly less in the first factor than the variation of K, Na, and the volatiles. Hence, the main igneous trend is obscured by alteration effects. In Figure 60.2a, it can be seen that the compositional trend that is related to feldspar fractionation in the tholeiites is shared between Factors 1 and 2. The cluster of points between Ca and Na represent the compositional variation related to feldspar composition, whereas the cloud of points that spread out toward K represent K–enriched altered tholeiites.

The third factor, contributing 13.9% of the variation, is dominated by Na, volatiles, and Ca, and probably represents Na alteration. Figure 60.2b shows that the Na–enriched samples are displaced from the main cloud of points that are associated with Ca. These Na–enriched samples may be the result of metamorphism on the sea–floor after deposition or later spilitization. Factors 4 and 5 account for 12% and 6.9% of the variation of the data, respectively, and are dominated by Fe in Factor 4 and Mg in Factor 5. Dynamic cluster analysis also separates the Fe– and Mg–tholeiites readily. However, as shown in Figure 60.2c, a plot of Factor 4 versus Factor 5 does not show two separate clusters, because the main tholeiite iron–enrichment trend obscures these two factors. Plotting of the group centres obtained during dynamic cluster analysis results in a similar plotting effect, although the individual groups are either Fe or Mg rich. It is possible that recalculation of the samples to anhydrous values, or elimination of the more highly altered samples in the dataset, or both, might enhance the separation of Factors 4 and 5 on a factor score plot.

TABLE 60.1. CORRESPONDENCE ANALYSIS OF 2536 ARCHEAN THOLEIITIC VOLCANIC ROCKS FROM ONTARIO.

Eigenvalues	% of Variation
0.02829635	36.02
0.01359913	17.31
0.01088275	13.85
0.00941263	11.98
0.00539962	6.87
0.00427933	5.45
0.00340296	4.33
0.00187122	2.38
0.00105392	1.34
0.00036209	0.46

ABSOLUTE AND RELATIVE CONTRIBUTIONS OF THE VARIABLES

	WEIGHT	AC(1)	RC(1)	AC(2)	RC(2)	AC(3)	RC(3)	AC(4)	RC(4)	AC(5)	RC(5)
Si	0.529411	4.17	51.82	0.11	0.64	4.54	21.69	2.22	9.19	7.03	16.66
Al	0.148017	0.40	24.26	1.24	36.07	0.00	0.06	1.95	39.40	0.02	0.21
Fet	0.107105	8.56	27.85	0.10	0.16	0.00	0.00	66.36	71.82	0.28	0.18
Mg	0.054280	8.03	34.37	0.85	1.75	3.21	5.29	1.76	2.51	68.64	56.07
Ca	0.079821	23.28	62.03	5.76	7.38	14.77	15.14	12.43	11.01	8.72	4.44
Na	0.025865	0.30	1.37	6.59	14.66	39.91	71.01	3.27	5.03	8.99	7.94
K	0.007435	43.23	68.11	37.06	28.06	3.54	2.15	1.33	0.70	3.27	0.98
Ti	0.011333	0.08	1.94	0.08	0.92	0.98	9.28	9.69	79.58	1.76	8.28
P	0.001240	0.43	55.82	0.02	1.48	0.48	23.68	0.09	3.68	0.62	15.34
Mn	0.001952	0.11	29.47	0.03	3.24	0.00	0.10	0.74	65.62	0.03	1.56
Vol	0.033542	11.41	24.15	48.16	48.98	32.56	26.50	0.16	0.11	0.63	0.26

Unlike the komatiite suite (Grunsky *et al.* 1987), the tholeiites show less hydration overall, and the main igneous trend is clearly shown in the first factor. With respect to designing effective discrimination diagrams, it would appear that Ca, Fe, and Mg would be critical elements in separating the main groups of tholeiitic volcanic rocks from other volcanic suites. Plots using Na and K as parameters are likely to reflect alteration effects rather than primary igneous trends. This point is discussed later in the text under discussion of the combined komatiite–tholeiite–calc–alkalic–alkalic dataset.

CALC–ALKALIC SUITE

The calc–alkalic data base comprises 1325 samples, mainly from the Abitibi Greenstone Belt. Results of correspondence analysis are tabulated in Table 60.2, and illustrated in Figures 60.3a and 60.3b. The primary factor accounts for 56.8% of the observed variation in the data, higher than for the tholeiites, and reflects the main petrogenetic trend of the suite, being controlled by variation in Fe, Ca, Mg, Si, and K. Factor 3, which accounts for 13% of the variation, is dominated by volatiles (70%) and K (15%) and is considered to represent an alteration effect. This is clearly seen on Figure 60.3a, with the diffuse cloud in the upper right and left hand quadrants representing this alteration. Unlike the tholeiites (Figure 60.2a), however, the degree of scatter is less in Figure 60.3a, reflecting the lesser significance of alteration in the calc–alkalic suite. This could be due to the greater abundance of intermediate and felsic rock–types in the calc–alkalic data base which are more resistant to low–grade alteration than are the komatiitic and tholeiitic rocks. This effect is possibly a function of a more stable low–temperature mineralogy, and less porosity in the intermediate and felsic rocks, as well as kinetic effects. Alternatively, these samples may not be a true representation of most calc–alkalic rocks present in the Superior Province. These samples were selected from the Blake River Group of the Abitibi Greenstone Belt and are only weakly metamorphosed and display little recrystallization. Calc–alkalic rocks from other greenstone belts within the Superior Province may be more altered, thereby displaying different chemical characteristics and multielement variation.

Factor 3, accounting for 9.8% of the variation, is dominated by K, Na, and Ca, probably reflecting variation amongst the felsic end members of the suite, with Factor 4, which is dominated by variation in Ca, Fe, and Mg reflecting the mafic end members. Factor 5, which only accounts for 4.1% of the observed data variation, is controlled by Na, Mg, and P, and may reflect the presence of misclassified alkalic rocks. As for the tholeiites, this slight difference is not readily observed on a plot of Factor 4 versus Factor 5 because of the overwhelming effect of the main igneous trend.

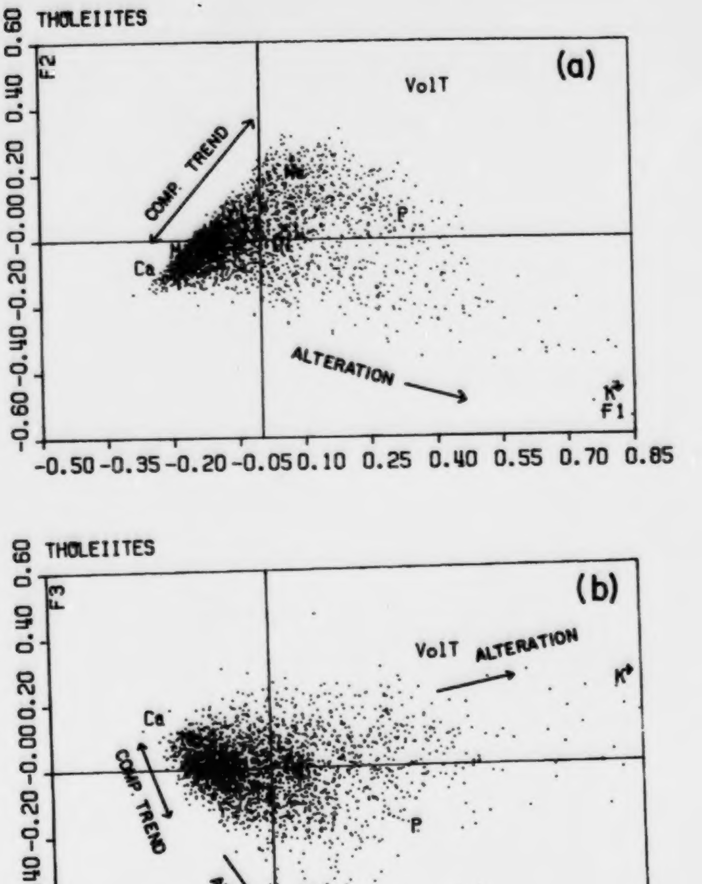

Figure 60.2. *Projection of sample and variable scores on various factor planes from correspondence analysis of 2536 Archean tholeiite volcanic rocks from Ontario: (a) Factor 1 versus Factor 2 plane; (b) Factor 1 versus Factor 3 plane; (c) Factor 4 versus Factor 5 plane.*

TABLE 60.2. CORRESPONDENCE ANALYSIS OF 1325 ARCHEAN CALC-ALKALIC VOLCANIC ROCKS FROM ONTARIO.

Eigenvalues	% of Variation
0.03373136	56.85
0.00822135	13.85
0.00578971	9.76
0.00446667	7.53
0.00243297	4.10
0.00179253	3.02
0.00156774	2.64
0.00070243	1.18
0.00051836	0.87
0.00012402	0.21

ABSOLUTE AND RELATIVE CONTRIBUTIONS OF THE VARIABLES

	WEIGHT	AC(1)	RC(1)	AC(2)	RC(2)	AC(3)	RC(3)	AC(4)	RC(4)	AC(5)	RC(5)
Si	0.606384	15.26	90.73	2.27	3.29	1.67	1.71	1.51	1.19	7.21	3.09
Al	0.165352	0.00	0.62	0.00	0.00	0.64	35.91	0.01	0.34	2.69	63.13
Fet	0.055913	23.66	88.96	0.04	0.04	1.61	1.04	19.75	9.83	0.51	0.14
Mg	0.030970	20.91	84.80	0.06	0.06	0.10	0.07	13.21	7.09	27.30	7.98
Ca	0.048555	21.18	69.21	6.46	5.15	14.04	7.87	37.56	16.25	6.48	1.53
Na	0.040139	0.49	6.61	0.38	1.24	16.56	38.23	9.53	16.98	38.05	36.93
K	0.012502	10.57	42.70	15.38	15.14	55.75	38.65	6.45	3.45	0.22	0.06
Ti	0.007667	1.99	86.00	0.02	0.16	0.10	0.73	1.12	6.41	2.15	6.70
P	0.001319	0.07	4.03	0.19	2.58	1.43	13.44	2.88	20.86	14.98	59.09
Mn	0.000991	0.38	85.64	0.01	0.42	0.12	4.77	0.11	3.31	0.36	5.86
Vol	0.030207	5.47	20.86	75.20	69.92	7.98	5.22	7.88	3.98	0.04	0.01

Unlike the tholeiitic and komatiitic suites, no clear sets of elements appear to be useful in characterizing variation within the calc–alkalic suite, or distinguishing it from other suites. However, the presence of Ca, Fe, and Mg as major components controlling some of the variation in the calc–alkalic suite indicates that separation of the tholeiites and calc–alkalic rocks is not clear cut, as might be expected from petrologic considerations (*see* discussion later in the text). Perhaps the most important distinction between the two suites is the trend that is established by a group of samples.

ALKALIC SUITE

Archean alkalic volcanic rocks in Ontario are found mainly in association with Timiskaming-type pull–apart basins and are best described from the Shebandowan area (Shegelski 1980).

The alkalic suite has only been investigated in a preliminary manner, and the data base consists of only 76 samples. The small number of samples reflects the difficulty in selecting Archean alkalic rocks that have been classified using conventional means. Accordingly, the working group did not use any specific chemical criteria in selecting the alkalic rocks used in this analyses, rather, samples were selected which were well constrained by field work as being part of the classical Archean alkalic volcanic association.

Although of limited statistical validity, the working group's preliminary results show that 41% of the variation is accounted by the first factor which is controlled by K (50%), Fe (21.4%), and Ca (10.7%). Factor 2 (21.7% of the variation) is an alteration trend, dominated by Na and volatiles, as is Factor 3 (14.7% of the variation) which is dominated by volatiles. Factor 4 (8.5%) is controlled by Ca, Fe, Mg, and Ti, and probably reflects variation amongst the more mafic members of the suit. Factor 5 (6.6%) may reflect the presence of carbonatized rocks, as Ca and Mg are the dominant elements. Some general effects are seen in the alkalic suite as for the tholeiites and the calc–alkalic rocks. Factor 1 is the main igneous trend, Factor 2 is an alteration trend, and Factor 4 is Fe dominated. This order may not be fortuitous, instead it probably reflects the relative significance of primary igneous trends, alteration effects, and the abundance of iron (oxidation or iron carbonate alteration) in any igneous suite.

COMBINED DATASETS

The true utility of multivariate techniques for rock classification becomes apparent when the four suites are combined into one dataset. The results of analysis of a combined dataset of 209 komatiites, 2536 tholeiites, 1325 calc–alkalic, and 76 alkalic rocks is tabulated in Table 60.3 and illustrated in Figures 60.4a, 60.4b, 60.4c.

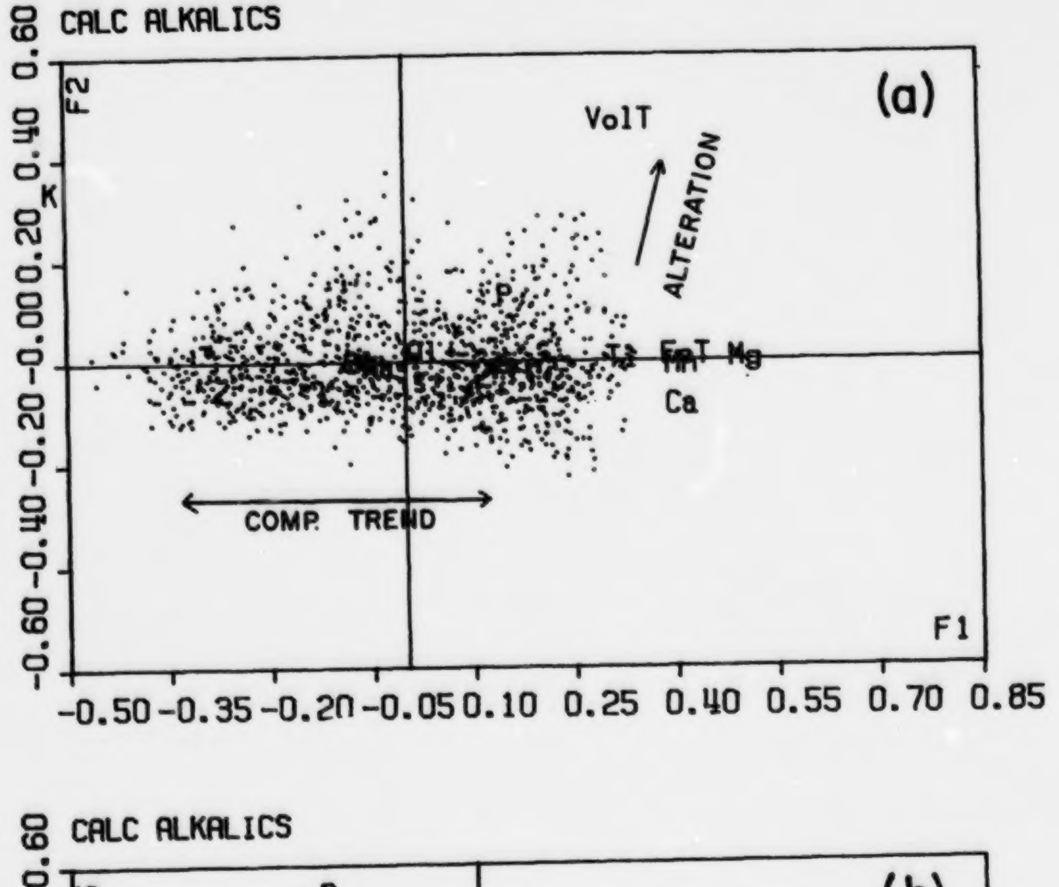

Figure 60.3. *Projection of sample and variable scores on various factor planes from correspondence analysis of 1325 Archean calc-alkalic volcanic rocks from Ontario: (a) Factor 1 versus Factor 2 plane; (b) Factor 4 versus Factor 5 plane.*

TABLE 60.3. CORRESPONDENCE ANALYSIS OF 4146 ARCHEAN KOMATIITES, THOLEIITES, CALC-ALKALIC, AND ALKALIC VOLCANIC ROCKS FROM ONTARIO.

Eigenvalues	% of Variation
0.05622677	46.34
0.02267212	18.69
0.01242428	10.24
0.01105654	9.11
0.00814435	6.71
0.00444806	3.67
0.00300068	2.47
0.00202724	1.67
0.00101076	0.83
0.00031760	0.26

ABSOLUTE AND RELATIVE CONTRIBUTIONS OF THE VARIABLES

	WEIGHT	AC(1)	RC(1)	AC(2)	RC(2)	AC(3)	RC(3)	AC(4)	RC(4)	AC(5)	RC(5)
Si	0.550475	9.46	83.56	0.83	2.97	6.88	13.43	0.00	0.01	0.03	0.03
Al	0.149823	3.88	85.28	1.19	10.54	0.04	0.20	0.16	0.69	1.03	3.28
Fet	0.090106	12.00	45.03	13.77	20.83	19.73	16.35	0.06	0.04	32.65	17.74
Mg	0.054693	52.14	79.87	25.50	15.75	10.4	83.55	2.27	0.68	0.69	0.15
Ca	0.069169	8.93	35.00	23.03	36.40	0.18	0.16	4.16	3.21	44.44	25.23
Na	0.029703	4.88	52.18	0.02	0.08	8.43	19.90	8.82	18.53	6.02	9.31
K	0.009341	7.72	27.92	17.06	24.87	19.51	15.58	44.49	31.63	0.00	0.00
Ti	0.009785	0.06	2.27	2.45	38.58	3.29	28.35	0.23	1.78	5.13	29.01
P	0.001274	0.10	30.39	0.04	5.04	0.77	54.67	0.01	0.78	0.20	9.11
Mn	0.001629	0.17	39.63	0.29	28.22	0.42	22.29	0.02	1.09	0.25	8.77
Vol	0.034002	0.66	2.89	15.81	27.80	30.28	29.18	39.77	34.10	9.56	6.04

The first factor, accounting for 46.3% of the observed variation, is controlled by Mg and Fe, and separates the komatiite suite from the subalkalic rocks (Figure 60.4a). Factor 2 (18.7%) of the observed data variation is Mg, Ca, K, and Fe controlled, and consists of samples of the tholeiitic and calc–alkalic suites which are not clearly separated on a Factor 1 versus Factor 2 plot (Figure 60.4a). Factors 3 and 4 (10.2% and 9.1% of the variation, respectively) are alteration effects, with Factor 3 controlled by hydration and Factor 4 showing potassium alteration and hydration. Ti and P are also contributors to Factor 3, and as shown in Figure 60.4b, the plot of Factor 1 versus Factor 3 comes closest to separating the alkalic from the subalkalic rocks. The diffuse nature of the plots of the subalkalic rocks in Figure 60.4b reflects this alteration. Factor 5 reflects iron–rich subalkalic rocks (Ca and Fe are dominant in this factor), probably representing Fe rich tholeiites, an observation to be verified by subsequent work. As shown in Figure 60.4c, a plot of Factor 1 and Factor 5 does not separate the subalkalic rocks effectively, since Factor 5 reflects a sub–grouping of the main igneous trend shown by Factor 1.

It is clear from Figure 60.4 that the komatiite suite can be readily distinguished from the subalkalic and alkalic rocks. As might be expected from petrologic principles, separation of the tholeiites and calc–alkalic clans is more difficult; however, the multivariate technique does indicate that each suite has discrete end–members, even though there is considerable overlap.

In a study of modern circum–oceanic volcanic rocks, namely, tholeiites (iron–enrichment trend), calc–alkalic rocks (hypersthene in groundmass pyroxenes), and nepheline–normative rocks, Johnston *et al.* (1978) could not clearly distinguish between the three groups using standard binary and ternary diagrams and factor analysis. In some areas, calc–alkalic rocks formed a continuum with shoshonites, elsewhere they formed a continuum with tholeiites. Johnston *et al.* (1978) suggested that such "artificial" world–wide distinctions as tholeiitic and calc–alkalic suites were of limited use in describing regional magmatic variations. The working group seems to be seeing similar effects, and it is for this very reason that the working group's approach has been one of attempting to understand the chemical variation present wholly in Archean suites prior to attempting comparisons with modern suites. For practical purposes, however, the group has focused on the four historically described Archean magmatic suites (komatiitic–tholeiitic–calc–alkalic–alkalic), although the group may subsequently recommend a different type of classification.

Figures 60.5a, 60.5b, and 60.5c show how rocks of the various suites compare on standard variation diagrams. In this case, only 100 samples of representative komatiites, tholeiites, and calc–alkalic rocks

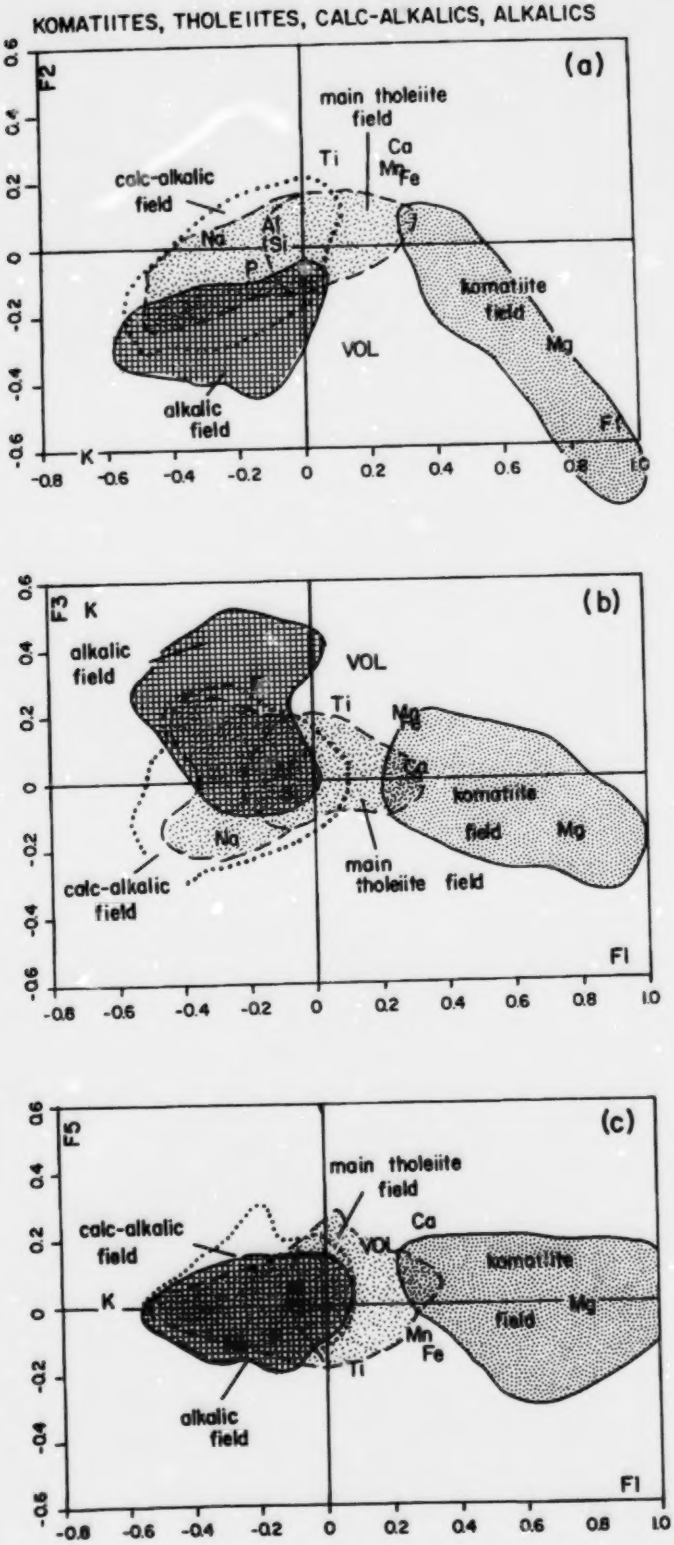

Figure 60.4. *Projection of sample and variable scores on various factor planes from correspondence analysis of 4146 Archean komatiite, tholeiite, calc-alkalic, and alkalic rocks from Ontario. Main tholeiite field designated on plots refers to area where over 60% of the tholeiites plot. Discrimination between the main tholeiite field and the calc-alkalic field is better than for the full range of tholeiites: (a) Factor 1 versus Factor 2 plane; (b) Factor 1 versus Factor 3 plane; (c) Factor 1 versus Factor 5 plane.*

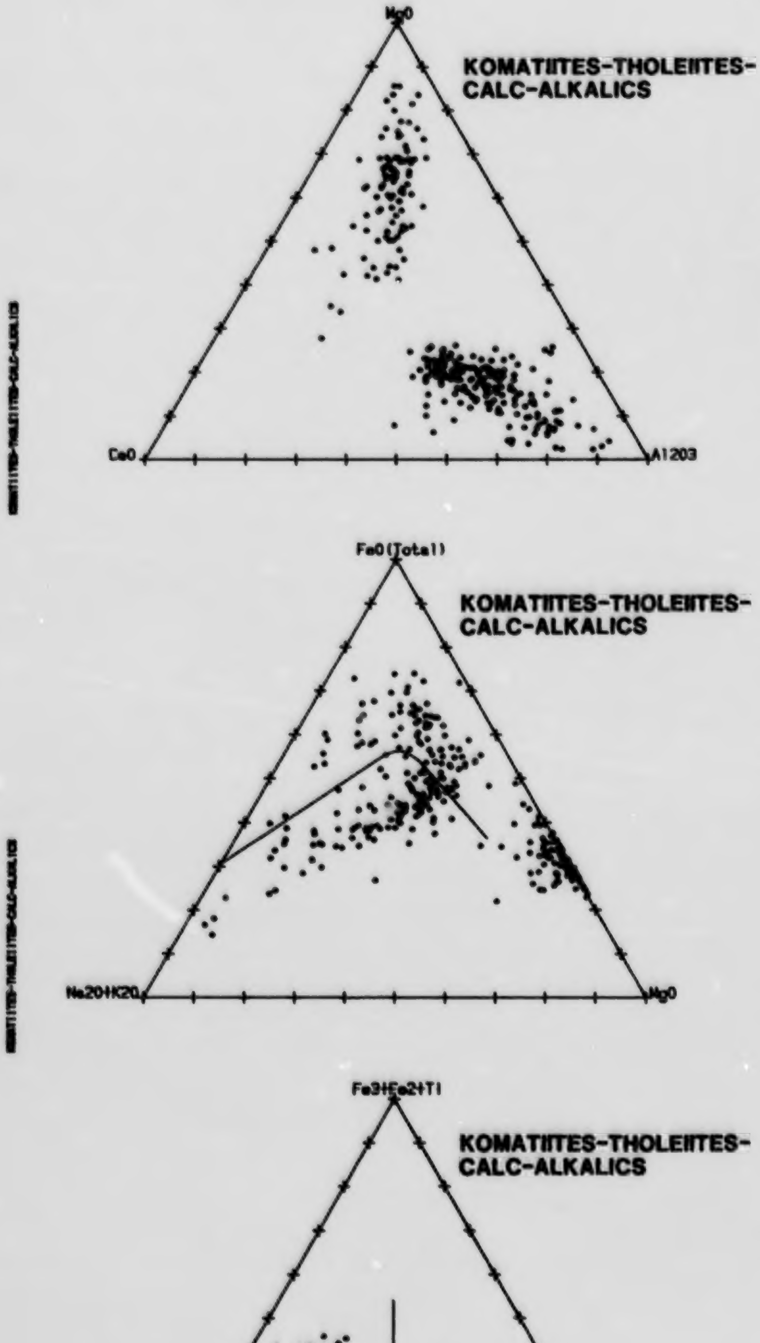

Figure 60.5. *(a) CaO-MgO-Al_2O_3 ternary plot of 100 komatiites, 100 tholeiites, and 100 calc-alkalic volcanic rocks. The komatiites are distinct from the tholeiitic and calc-alkalic rocks, however, this diagram does not separate the calc-alkalic and tholeiitic rocks. Multivariate statistical analysis predicts that Ca, Mg, and Al are the elements which best describe the behavoir of the komatiitic rocks with respect to the subalkalic rocks. See text and Grunsky et al. (1987) for further details; (b) AFM (Na_2O + K_2O-$FeO(t)$-MgO) ternary diagram of 100 komatiites, 100 tholeiites, and 100 calc-alkalic volcanic rocks. Compositional variation in the komatiites is not well displayed. Tholeiites and calc-alkalic rocks are separated and show a wide range of compositional variation. Diagram is very susceptible to alteration effects, which can affect the classification of tholeiitic versus calc-alkalic rocks; (c) Jensen (Al-Fe + Ti-Mg) ternary diagram of 100 komatiites, 100 tholeiites, and 100 calc-alkalic volcanic rocks. This diagram is a compromise between the compositional variation displayed in the other two ternary figures.*

are shown. As noted by Grunsky *et al.* (1987), Mg, Ca, and Al control igneous variation in the komatiite suite, hence the CaO–MgO–Al_2O_3 ternary (Figure 60.5a) is useful in separating komatiites from the subalkalic rocks. As noted earlier in this paper, Ca is a significant element in both the tholeiitic and calc–alkalic suites, hence, the CaO–MgO–Al_2O_3 is not effective in discriminating these suites. The AFM plot (Figure 60.5b) is of limited effectiveness, in part because it does not display Ca variation, and in part because Na and K are likely to be affected by alteration, which is a significant factor in all of the suites. The Jensen plot (Figure 60.5c) is more effective than the AFM diagram because it eliminates to some degree the effects of alteration, and can separate komatiitic and subalkalic rocks.

FUTURE WORK

Work over the past year has been promising, and it is clear that multivariate techniques can be a used successfully to classify Archean volcanic rocks, in part because it is capable of discriminating between the different suites, and in recognizing a variety of alteration trends in a particular group of samples. The difficulties found in classifying some of the subalkalic and alkalic rocks are not unexpected given petrologic principles. In particular, the difficulty in classifying Archean alkalic rocks reflects more on the poor state of knowledge of these rocks then inherent problems in the method.

Work in 1989 will continue on preparing the data bases for publication, examining classification problems of the subalkalic and alkalic rocks, and in testing a variety of binary and ternary variation diagrams, both existant and of the working group's own design based on interpretation of their statistical results. The group also hopes to be able to include a variety of trace elements into its studies, particularly with respect to distinguishing rocks of the tholeiitic, calc–alkalic, and alkalic suites. Ultimately, the working group hopes to be able to construct a number of datasets typical of the various suites, so that small groups of samples can be combined with a known suite, and discriminated accordingly using multivariate techniques. In this way, the working group hopes to be able to adapt these methods to datasets commonly encountered by the average field and to identify simple techniques which are effective in distinguishing the different types of chemical variation observed in Archean (and younger) volcanic rocks.

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Engineering and Terrain Geology Programs

61. Summary of Activities of the Engineering and Terrain Geology Section, 1988

C.L. Baker

Supervisor, Quaternary Geology Subsection, Engineering and Terrain Geology Section, Ontario Geological Survey, Toronto.

INTRODUCTION

During the 1988 field season, the Engineering and Terrain Geology Section undertook 16 field projects. Activities took place in all areas of the province from Windsor to the James Bay Lowland, and Fort Frances to Matheson.

Nine of the Section's projects involved geological mapping at various scales. These supply both the government and private sector with a data base suitable for land use planning and resource exploration. This type of mapping is in line with the Ontario Geological Survey's mandate to delineate and characterize the geological materials within the province.

QUATERNARY SUBSECTION

The Quaternary subsection was involved in nine projects. Six of these projects cover basic Quaternary mapping, two emphasize reconnaissance till sampling, and one applied research project examined airborne radar applications in Quaternary mapping.

Mapping was started in the Essex County area of southern Ontario by T.F. Morris to determine the environment and mode of deposition of Quaternary sediments. Such information is important in delineating the extent of materials both at ground level and in the subsurface. Morris' recognition of the sand and gravel comprising the Leamington Moraine as preglacial sub–aqueous fan deposits has implications in the search for additional aggregate resources in the area. Understanding of the stratigraphic sequence in the area is critical for effective land management decisions such as those related to the siting of sanitary landfills.

Mapping in the adjacent Wheatley area was undertaken by R.I. Kelly. Mapping of the surface sediments and features will be integrated with extensive information from the bluff sections on the Lake Erie shoreline to provide an understanding of stratigraphic relationships. This is an important factor given the large tracts of flat undissected land within the project area. Planning requirements in the Wheatley area are similar to Essex County, particularly the scarcity of aggregate resources. Knowledge of the distribution and characteristics of the surficial materials will have equivalent benefits.

P.J. Barnett continued mapping in the Barrie–Elmvale area, Simcoe County. The 1:50 000 scale mapping is revealing a complex glacial history including three till units with associated glaciolacustrine sediments. Barnett's work is leading to the development of an original hypothesis concerning glacial and glaciofluvial processes and deposits in the area. This work could change our understanding of ice mass dynamics in the Great Lakes area during the final phase of the last glaciation. Such ideas may seem academic, however, the occurrence of glaciofluvial material has a strong and direct impact on land values, planning, and development. Pre– and post–glacial features of note in the Barrie–Elmvale area are the solution weathering (karst) on the Paleozoic bedrock surface and the numerous glacial lake shorelines.

P.S.G. Kor's mapping in the Sundridge–Burk's Falls area is a continuation of his previous two years' work to the west. In general, the volume of Quaternary deposits increases eastward from the shore of Georgian Bay, although the thickness of glacial sediments in any of his study areas is not great. Kor's work will a) delineate the distribution of materials, including aggregate; and b) determine the composition and character of the various sediments. This information will advance understanding of the glacial history of the area and the relationships of the surficial sediments.

Work in the Shining Tree area was completed by P.W. Alcock. This area is covered by extensive glacial deposits and will be of major interest in mineral exploration overburden sampling programs. Detailed knowledge of the type and transport history of surficial sediments is needed to establish methodologies suitable to the geological conditions and to ensure that data are interpreted correctly. Till sampling from this project will provide valuable assistance for detailed mineral exploration programs.

F.J. Kristjansson completed field work in the Beardmore–Geraldton–Longlac area. This study was a joint program with the Geological Survey of Canada. The work was undertaken in several overlapping stages: Quaternary mapping, surface till sampling, and deep overburden drilling. The work has yielded several notable observations: a) the till in this area of northern Ontario has a complex transport and depositional history, b) the composition of the upper till unit in the area is due to a streaming effect in ice mass flow, and c) the lowest till unit is an excellent sampling medium for mineral exploration. The high number of gold grains recovered from the lower till unit indicates the area has a high mineral potential which can be investigated using drift prospecting techniques. Kristjansson's work also illustrates that effective overburden sampling programs require attention to the type and origin of the sediments being sampled.

In the Fort Frances–Rainy River area, A.F. Bajc completed the second and final phase of an overburden drilling project and in the Matheson area, the drill program supervised by K.G. Steele was the final stage of the five–year Black River–Matheson (BRIM) project. The sequence of field activities in both areas was Quaternary mapping at a 1:50 000 scale, backhoe trenching in areas of shallow drift followed by rotasonic drilling in areas of deep overburden.

The Fort Frances area is characterized by at least two ice flow directions, one from the northeast and the other from the west. The nature of the deposits associated with each advance is markedly different as is their use in drift prospecting programs. The more useful till unit is often buried; defining its distribution and continuity is part of Bajc's work. Geochemical assessment of the till samples will provide information on areas of mineral potential and exploration interest.

The Matheson area has long demonstrated a high mineral potential and has attracted considerable exploration interest. In recent years an increasing amount of work has taken place in areas of glacial cover. The results of the BRIM program have shown that interpreting overburden sample results is not an easy task as up to three drift packages are present in the region. The data gathered in the Matheson area will allow a determination of the ice directions associated with each advance and provide an exploration database that will be of use for the foreseeable future.

The work described by V.H. Singhroy and P.J. Barnett represents a commitment on the part of the Ontario Geological Survey to investigate new tools and techniques that may assist in the mapping of the province. Although the marriage between remote sensing and Quaternary geology is not new, the goal of finding methods that will allow rapid, yet accurate, mapping continues. The work presented by these authors, while preliminary, is intriguing and warrants continued study.

PALEOZOIC SUBSECTION

The Paleozoic Subsection undertook three field projects in 1988. Two of these represent basic geoscience and mineral deposit inventory, and the third represents applied research.

Demand for rock derived resources such as building and crushed stone is rapidly moving outward from the population centres of southern Ontario.

D.K. Armstrong's mapping in the central Bruce Peninsula will delineate and evaluate potential resources in the Bruce Peninsula now, as a basis for effective land use and zoning decisions in the future. Based on Armstrong's observations of numerous karst features on the Paleozoic surface, care must be taken when planning susbsurface investigations. Karst structures can affect the design requirements and performance of man–made structures.

The project completed by R.K. Bezys provides an evaluation of gypsum deposits in the James Bay Lowland. The gypsum resources of the Moose River Basin have been known for sometime, however, their setting and geology were poorly documented, thus their potential was unclear. Bezys' work describes and defines the surface extent of the gypsum beds to assist exploration and development interest in the deposits. This study will provide a geological report identifying the potential resource supply which will compliment a market evaluation study being carried out by the Mineral Development Section, Mineral Development and Lands Branch.

Applied research work carried out by G.H. McFall, O.L. White, and A. Allam in Prince Edward County on bedrock structural features is unique in its scope and design. The authors are investigating neotectonic activity as reflected by post–glacial (?) faults and stress relief features (pop–ups). The investigation was undertaken by a variety of methods including field mapping, remote sensing, and geophysics. Perhaps the most interesting implication of this work is that if large tracts of bedrock, which traditionally have been considered stable, are shown to be subject to neotectonic activity, it will have direct repercussions on the planning and siting of environmentally sensitive structures.

AGGREGATE ASSESSMENT OFFICE

Four projects involving field work were completed by the staff of the Aggregate Assessment Office. Three of these are basic mineral resource inventories while the fourth project involves some applied research.

C.J. Dawson and S. Szoke's work in Peterborough County confirmed the limited Quaternary gravel resources in the area. In this county, the shortage is so severe that weathered Grenville gneisses have been used as road fill. The Paleozoic Gull River Formation occurs in the county and is quarried as a source of crushed aggregate but care must be taken to avoid alkali–carbonate reactive beds during extraction. Much the same situation exists in Victoria County, however, some deposits containing limited amounts of gravel are present. The Middle Ordovician Bobcaygeon and Gull River formations provide sources of crushed stone available for extraction.

The aggregate inventory of the towns of Bracebridge and Gravenhurst is reported by R.G. Gorman and S. Szoke. Aggregate information in this area is required for land use planning decisions. The authors report that the study area contains large sand resources and limited amounts of gravel. The gravel is found within Quaternary glaciofluvial outwash and ice–contact deposits as well as deltaic deposits.

The work of G.R. Jones and S. Szoke identifying the aggregate resources northwest of Fort Frances was undertaken for the purpose of locating quality aggregate sources for future forest access road construction. This information is also useful in selecting the routes so that haul distances can be kept to a minimum. Potential sources of aggregate located in the area include moraines, the largest of which is the Rainy Lake–Lake of the Wood Moraine, eskers, and ice–contact ridges. The identification of these features will help alleviate potential sand and gravel shortages in the area.

An applied research project being carried out by D.G. Vanderveer and S. Szoke examines the problem of defining aggregate resources buried by other non–economic materials. The work involves developing methods and techniques which can locate and delineate buried aggregate deposits. The Pinehurst and Leamington gravel deposits in southwestern Ontario have been used as test sites. Issues surrounding the development of these deposits illustrate some of the aggregate related problems in this part of the province: a general scarcity of high.quality material, conflicting land use demands, and environmental concerns.

62. Project Number 88–4. Quaternary Geology of Essex County, Southern Ontario

T.F. Morris

Geologist, Engineering and Terrain Geology Section, Ontario Geological Survey, Toronto.

INTRODUCTION

Mapping of the Quaternary geology of Essex County was initiated in the summer of 1988 (Figure 62.1). Mapping east of Longitude 82°52′30″W and west of Longitude 82°30′W, and between Latitudes 41°40′30″N and 42°20′N (refer to 1:50 000 scale NTS map sheets; Essex (40J/2), Belle River (40J/7), Pelee Island (40G/15), and Middle Island (40G/10)), was completed by the end of August 1988. Mapping of the western part of Essex County will be completed in 1989.

Vagners (1972) previously mapped the Quaternary geology of Essex County and defined the distribution of surficial deposits and shoreline features. This mapping project will produce a report describing the distribution and origin of surficial materials. The origin of materials will be determined by examining their sedimentology, stratigraphy, morphology, and distribution. Laboratory analysis (including petrology, grain size, carbonate content, clay mineralogy, geochemistry, and heavy minerals) of materials will assist in the separation and fingerprinting of units.

PHYSIOGRAPHY AND BEDROCK GEOLOGY

The study area is primarily an extensive clay plain with little relief (Chapman and Putnam 1984). Wells drilled through the clay indicate that depth to bedrock varies between 9 m and 45 m (Vagners *et al.* 1973). The shallowest drift is located near Amherstburg where a dome of limestone subcrops (Chapman and Putnam 1984). Bedrock outcrops only on the northwestern and southeastern corners of Pelee Island.

The Middle Devonian Sylvania Formation sandstone and Amherstburg and Lucas Formation dolostones/limestones of the Detroit River Group underlie the southern half of Essex County and the east bank of the Detroit River. The limestones of the Dundee Formation and the shales of the Hamilton Group (Telford and Russell 1981) underlie northern Essex County, Point Pelee, and Pelee Island. The Silurian Bass Island Formation dolostone underlies the area along the north shore of Lake Erie, northwest of Colchester.

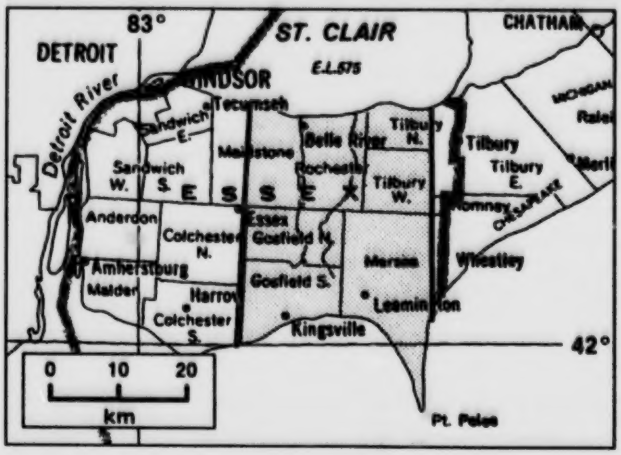
83°
DETROIT
ST. CLAIR
E.L.575
CHATHAM
WINDSOR
Detroit River
Tecumseh
Sandwich E.
Maidstone
Belle River
Tilbury N.
Tilbury
Tilbury E.
Sandwich W.
Sandwich S.
Rochester
Tilbury W.
E S S E X
Romney
Anderdon
Colchester N.
Essex
Gosfield N.
Mersea
Wheatley
Amherstburg
Malden
Harrow
Gosfield S.
Leamington
Colchester S.
Kingsville
42°
0 10 20
km
Pt. Pelee
Raleigh
Merlin

Figure 62.1. *Location map for Essex County, Southern Ontario.*

OBSERVATIONS ON THE GLACIAL GEOLOGY

Several key observations were made during the Quaternary mapping of eastern Essex County this past summer. Interpretation of field observations and data generated from laboratory analysis of collected samples should clarify the Quaternary history of eastern Essex County.

The oldest glacial deposit found in the study area is a red, clast–poor, massive, silty clay diamicton found below lake level at the foot of a bluff east of Kingsville. Capping this red diamicton is a thin (2 to 5 cm) organic bed. The organic bed is overlain by a grey, clast–poor, massive silty clay diamicton separated from a second similar diamicton by bedded sands. If the organics formed during the Erie Interstadial (Dreimanis and Karrow 1972), deposition of the red diamicton occurred during the Nissouri Stadial (or earlier), and the overlying diamictons and bedded sand were deposited during the Port Bruce Stadial. Alternatively, if the organic layer was deposited during the Port Talbot or Plum Point interstadials, deposition of the red diamicton occurred during the Early Wisconsinan, and the overlying diamictons and bedded sands during the Nissouri and/or Port Bruce stadials.

North of the bluffs, an aggregate operation, known locally as the Bondi pit, is located in what is probably a proglacial delta. The stratigraphy and sediments within this delta indicate that its development was influenced by the ice–marginal positions of ice flowing from both the Lake Erie and Lake Huron basins. Shells and organics deposited on top of a grey, clast–poor, massive silty clay diamicton overlying bedded sands may represent the Lake Whittlesey–Lake Arkona transition (Barrett 1985).

North of the Bondi pit, three man–made excavations provide excellent exposures. The general sequence observed in all three excavations is a grey, clast–poor, massive silty clay diamicton capped by a reddish–brown, rhythmically laminated silty clay with red clay "clasts". The structure and fabric of the lower grey diamicton suggests that it is a till deposited by ice flowing south from the Lake Huron Basin. The reddish–brown rhythmically laminated silty clay is probably glaciolacustrine in origin, deposited as ice retreated northward into the Lake Huron basin.

The most impressive landform within the study area is a large kidney–shaped body of sand northwest of Leamington in which there are a number of excavations (including the Bondi pit). A similar deposit is located farther west, south of Harrow. These deposits are probably proglacial subaqueous deltas. Northwest of the Leamington sand deposit is an extensive cobbly sand deposit which is probably proglacial subaqueous outwash. This subaqueous outwash was likely deposited by meltwaters originating from ice flowing out of the Lake Huron basin as indicated by the presence of jasper conglomerate and tillite within the cobbly sand.

Buried and partially buried glacial features are located on top of the Leamington sand deposit. These include: a) an esker net (oriented north–south); b) at least one proglacial subaqueous outwash fan; and c) a possible moraine. Other ridges composed of gravel and sand are located around the base of the Leamington sand deposit, and inland from the north shore of Lake Erie. When the orientations of these ridges are plotted, they define a series of ice–marginal positions indicating northward ice retreat. There are at least two north–south–trending eskers (possibly a third) located north and east of the Leamington sand deposit.

Weathered brown/grey glaciolacustrine silty clay which occurs north of Harrow and Leamington is occasionally mantled by thin deposits (<20 cm) of sand and/or gravel. The distribution of these sand and/or gravel deposits also defines recessional ice front positions.

Large grooves and flutes occur on outcropping bedrock at four locations on Pelee Island. Their orientations vary from 265° to 275°. Striae located at South Bay, Pelee Island indicate at least two flow directions; one set oriented at 190° is cut by a second set oriented at 265°.

Several beach sand ridges occur parallel to the shorelines of lakes St. Clair and Erie. On the surface of one sand ridge east of Leamington, shells were found and collected for radiocarbon dating.

Shells and organics were found 1 km east of the Albuna Township line road and 0.5 km north of the fourth concession. A farmer reported finding a mastodon tooth in sediments of a dried–up pond. Shells and cedar wood were collected from these pond sediments 1 m below the surface.

A prominent northwest–trending ridge underlies the towns of Cottam, North Ridge, and Essex. In the northwest, the ridge core is composed of a silty clay diamicton as observed in two house excavations in the town of Essex. The eastern side of the ridge drops sharply and is mantled by a layer of beach sand greater than 1 m thick which thins to 20 cm less than 0.5 km from the ridge. The western side of the ridge has a gentler slope and is mantled by a cobbly sand which is probably glaciolacustrine in origin. The cobbly sand grades into a weathered glaciolacustrine silty clay within 2 km of the ridge.

RELATED RESEARCH

Several related Quaternary geological mapping projects within Essex County and the surrounding area have recently been completed or are in progress. These include: a) a B.Sc. Thesis on the lithology, structure and stratigraphy of the upper clayey diamicton from three boreholes drilled in the

Courtright–Port Lambton area (Ansell 1988); b) a B.Sc. Thesis examining heavy minerals from till samples collected in Essex and Kent counties (Arroyes 1988); c) an M.Sc. Thesis on the Bedford Formation and overlying Quaternary sediments in the Lake St. Clair region (G. Brown, Department of Geology, University of Western Ontario, personal communication); and d) an Ontario Geological Survey mapping project for the Chatham–Wheatley area (Kelly, this volume).

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63. Project Number 88–26. Quaternary Geology of the Wheatley Area, Southern Ontario

R.I. Kelly

Geologist, Engineering and Terrain Geology Section, Ontario Geological Survey, Toronto.

INTRODUCTION

The Wheatley area is situated between Latitudes 42°15′ and 42°00′N and Longitudes 82°00′ and 82°30′W. The towns of Wheatley and Merlin are located within the map area (NTS 40 J/1). Lake Erie occupies the southeastern corner of the map sheet (Figure 63.1).

Quaternary geological mapping of the Wheatley area was previously undertaken by Sado (1981). Additional mapping was conducted in the area during the summer of 1988. Emphasis was placed on the collection of surface information and on the examination of bluff sections exposed along the north shore of Lake Erie. Examination of bluff sections was conducted to examine stratigraphic relationships and sedimentological characteristics of the exposed Quaternary deposits.

PHYSIOGRAPHY

The map area lies within the physiographic region of the St. Clair Clay Plain as described by Chapman and Putnam (1984). This region has been subdivided by these authors into the Essex Clay Plain, Lambton Clay Plain, Chatham Flats, and St. Clair Delta. The Essex Clay Plain is the only subregion present in the map area.

The Essex Clay Plain is essentially a low relief till plain smoothed by the action of glacial lakes which covered the area following final glacial retreat. The low relief of the area and the fine texture of the soils result in poor natural drainage. As a result, the use of tile drains throughout the area is extensive.

The continuity of the clay plain is interrupted by a thin, discontinuous cover of glaciolacustrine sand and silt near the town of Wheatley which extends southwest to the sand spit of Point Pelee.

A gravel–rich ridge rises a few metres above the clay plain east of Wheatley and extends eastward to the map boundary. Highway 3 closely follows the trend of this ridge. Also present in the eastern part of the map area are a series of low relief stoney ridges which parallel the southwest trend of the Blenheim Moraine. The main body of this moraine is located to the east of the map area.

The economy of the area is based primarily on agriculture. The warm climate and long growing season allow for the production of a wide variety of ten-

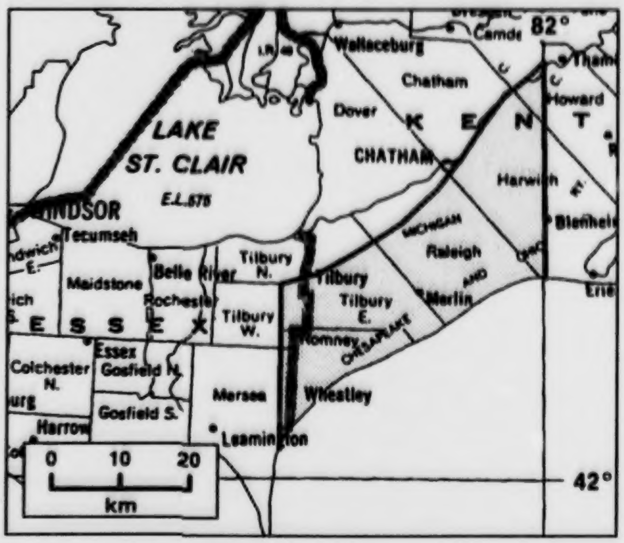
Wallaceburg
82°
Chatham
Howard
Dover
K E N T
LAKE ST. CLAIR
E.L.575
CHATHAM
Harwich
Blenheim
Tecumseh
Raleigh
Maidstone
Belle River
Rochester
Tilbury N.
Tilbury
Tilbury E.
Merlin
E S S E X
Tilbury W.
Romney
Essex
Colchester N.
Gosfield N.
Mersea
Wheatley
Gosfield S.
Harrow
Leamington
Erie
0 10 20
km
42°

Figure 63.1. *Location map for the Wheatley Area.*

der fruits and vegetables in addition to more traditional crops.

BEDROCK GEOLOGY

The map area is underlain by Middle and Upper Devonian shales and limestones. Middle Devonian limestone of the Dundee Formation subcrops in the southwestern corner of the map sheet near the town of Wheatley and further east near the hamlet of Port Alma. Shales and limestones of the Middle Devonian Hamilton Group overlie the Dundee Formation. The Hamilton Group subcrops over much of the western half of the map sheet and also in the extreme eastern part. The youngest rock unit in the area is the Upper Devonian Kettle Point Formation. The black shale of this formation covers most of the eastern portion of the map.

Throughout the area, the bedrock is overlain by thick deposits of Quaternary sediments. No bedrock outcrops are known to exist in the map area.

QUATERNARY GEOLOGY

The oldest glacial sediment exposed in this area is a clast poor, grey, clayey silt to silty clay till. This unit is present over much of the map area but is best exposed in Lake Erie bluff sections. Pebble fabrics and shear structures within this till indicate that it was deposited by ice which advanced northwestward out of the Erie Basin. This deposit has previously been attributed to the Port Bruce Stadial (Sado 1981).

The till for the most part is massive, contains shear planes, and exhibits a fissile nature. Stratified diamictons also occur within the massive till but more commonly overlie it. The stratified diamicton contains mud pellets and weakly developed lamination. A peculiar feature of the stratified diamicton is the presence of reddish coloured, clay–rich (diamicton) pellets and lenses up to 2 m in length. A similar reddish diamicton unit was also noted within some bluff sections just above lake level where it had been incorporated by the overlying massive grey till. This reddish diamicton unit has been reported further west near the town of Kingsville (Morris, this volume) where it underlies a thin layer of organic material. The age of this organic material is unknown but may be of early Late Wisconsinan age, that is, belonging to the Erie Interstade (Dreimanis and Karrow 1972). If this speculation is correct, then the reddish diamicton incorporated into the massive grey till could represent a Nissouri Stade or earlier deposit.

Following the retreat of glacial ice from the area, a series of proglacial lakes formed and covered southwestern Ontario. In the area surrounding Wheatley, glaciolacustrine sands and silts accumulated mantling the till. These sediments are often thin and discontinuous. Eolian action subsequently modified these materials in some areas. Glaciolacustrine gravels and sands also formed a low relief beach ridge which parallels the present day Lake Erie shore. This ridge extends from east of Wheatley to the eastern edge of the map sheet.

Glaciofluvial sediments are present in the extreme eastern part of the map sheet. Bluff sections near the hamlet of Dealtown reveal a 5 to 15 m thick coarsening up sequence of rhythmically bedded silts and clays, rippled sands, and crossbedded gravels and sands. Paleocurrent analysis from sections indicates paleoflow to the southwest. This coarsening up sequence is overlain by glaciofluvial gravels which formed a narrow southwest trending ridge. This ridge ends at the lake bluffs and extends northeastward through the hamlet of Cedar Springs.

ECONOMIC GEOLOGY

The map area is largely devoid of large, good quality surface aggregate deposits. Remaining gravel resources are concentrated in a narrow, thin beach ridge deposit which parallels Highway 3 and the Lake Erie bluff. Sand deposits are concentrated in the Wheatley area. The discontinuous nature and thinness of these deposits makes them an uneconomical resource.

Buried aggregate resources exist in the extreme eastern part of the map sheet. Examination of bluff sections in this area reveal the presence of thick (5 to 15 m), largely sand–rich deposits. The extent and thickness of these deposits inland is unknown.

The production of oil and gas in this area has continued since the last century. Recent discoveries of oil in Ordovician strata near Wheatley has spawned an increase in drilling. The apparent success of this activity will likely ensure continuation of exploration and drilling for a number of years to come.

RELATED RESEARCH

The Lake Erie bluffs provide the best subsurface exposures of Quaternary sediments in the map area. These bluffs are the focus of a B.Sc. Thesis by K. O'Keefe at the University of Guelph. Her work will concentrate on the stratigraphy and sedimentology of the sediments present in the bluffs.

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64. Project Number 86–13. Quaternary Geology of the Eastern Half of the Elmvale Area, Simcoe County

P.J. Barnett

Geologist, Engineering and Terrain Geology Section, Ontario Geological Survey, Toronto.

INTRODUCTION

The eastern half of the Elmvale area is located between Latitudes 44°30′N and 44°45′N, and Longitudes 79°30′W and 79°45′W (Figure 64.1), and is portrayed on the eastern half of the Elmvale (31 D/12) National Topographic System (NTS) Map at a scale of 1:50 000. Field investigations by the author, assisted by Robin Campbell, occurred during the months of June and July.

PHYSIOGRAPHY

The eastern half of the Elmvale map area is located within two of the physiographic regions of southern Ontario as defined by Chapman and Putnam (1984): the Simcoe Uplands and the Simcoe Lowlands. The Simcoe Uplands are areas of broad rolling till plains separated by steep–sided, broad, flat–floored valleys (Chapman and Putnam 1984). The Simcoe Lowlands include these broad valleys as well as the low–lying area north and east of Coldwater. Up to 100 m of relief separates the Simcoe Uplands from the Simcoe Lowlands.

GEOLOGY

The part of the Simcoe Lowlands which lies north and west of Coldwater contains numerous outcrops of Precambrian clastic metasedimentary rocks and Ordovician clastic and carbonate rocks. The Black River Escarpment, which separates the main body of Paleozoic rocks from Precambrian rock outcrops, can be traced intermittently from Uhtoff, westward through Foxmead to Fesserton. Several outliers of Ordovician rocks occur north of the escarpment. Solution weathering (karst) is common on Ordovician carbonate rocks which outcrop or are partly covered by a veneer of drift. Grikes, solution runnels, and solutions pipes are the common features present (Barnett 1986).

The dominant surficial sediment in the Simcoe Lowlands is glaciolacustrine silts and clays. Till outcrops as isolated drumlins and as small areas of drumlinized till plain. The till is dominantly of subglacial origin and is highly variable in texture and composition due to the variability of local bedrock. Drumlin orientation and striation directions on outcrops indicate glacier flow toward the south–southwest.

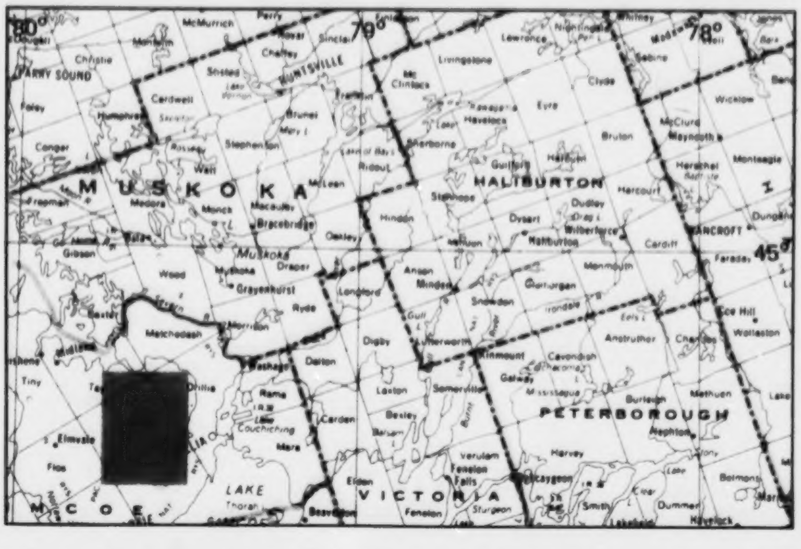
80°
79°
78°
45°
PARRY SOUND
MUSKOKA
HALIBURTON
PETERBOROUGH
VICTORIA
SIMCOE
HUNTSVILLE
BANCROFT
McMurrich
Perry
Sinclair
Chaffey
Christie
Stisted
Cardwell
Humphrey
Foley
Conger
Rosseau
Watt
Stephenson
Brunel
Ridout
McLean
Medora
Monck
Macaulay
Bracebridge
Oakley
Freeman
Gibson
Wood
Muskoka
Draper
Gravenhurst
Ryde
Morrison
Matchedash
Washago
Dalton
Longford
Tiny
Orillia
Rama
Lake Couchiching
Carden
Mara
Elmvale
Flos
Lake
Thorah
Beaverton
Eldon
Fenelon
Fenelon Falls
Verulam
Bexley
Laxton
Digby
Somerville
Lutterworth
Galway
Kinmount
Cavendish
Anson
Minden
Snowdon
Glamorgan
Hindon
Stanhope
Dysart
Haliburton
Guilford
Harburn
Sherborne
McClintock
Livingstone
Lawrence
Nightingale
Havelock
Eyre
Bruton
Clyde
Dudley
Wilberforce
Harcourt
Cardiff
Monmouth
Anstruther
Chandos
Burleigh
Methuen
Harvey
Smith
Dummer
Belmont
Havelock
Sturgeon
Bobcaygeon
Wollaston
Faraday
Dungannon
Herschel
Monteagle
McClure
Maynooth
Wicklow
Sabine
Whitney

Figure 64.1. *Location map for the eastern half of the Elmvale area, Simcoe County. Scale: 1:1 548 000 or 1 inch to 25 miles.*

The floor of one of the large valleys which divides the Simcoe Uplands is underlain by glaciolacustrine fine– to medium–grained sands, silts, and clays deposited during high level post–glacial lakes in the Lake Huron basin. More than six ancestral shoreline levels were observed during field mapping, including one level above the Main Algonquin level, as defined by Deane (1950).

The sediment types and relationships occurring within the Simcoe Uplands are much more complex. The surface sediment in the uplands is a sandy silt to silty sand diamicton with clasts consisting mainly of Precambrian rock types. It is commonly thinly bedded; associated with stratified sediments, and is believed to be of debris flow origin (flow tills). This sediment is often found in patches of low–relief, sinuous ridges that are orientated roughly north–south; the "ice–block ridges" of Deane (1950).

Three units of subglacial tills are present in the upland areas; each associated with and separated by glaciolacustrine sediments (Barnett 1986). As of yet, there is no indication of the absolute age of these subglacial till units.

ECONOMIC GEOLOGY

Ordovician bedrock is currently being extracted at Nelson Aggregates Quarry at Uthoff for numerous products, including crushed stone, agricultural lime, and armour stone. Crushed stone from the Coldwater Quarry is being used for road and bridge construction in the vicinity of Waubaushene. Extraction of sand and gravel resources occurs at 21 licensed sand and gravel properties within the eastern half of the Elmvale map area. Sand and gravel products are distributed locally, south to the Toronto market, and as far north as the Huntsville area (W.D. Fitzgerald, District Geologist, Ministry of Natural Resources, Midhurst, and R. Gorman, Resource Geologist, Ministry of Northern Development and Mines, personal communications, 1988).

Sand and gravel is being extracted predominantly from ice–contact stratified drift deposits, including eskers, and subaqueous fan deposits, and ancestral shorelines features.

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65. Project Number 86-16. Quaternary Geology of the Sundridge-Burk's Falls Area, Central Ontario

P.S.G. Kor

Geologist, Engineering and Terrain Geology Section, Ontario Geological Survey, Toronto.

INTRODUCTION

Quaternary mapping of the area east of Georgian Bay, conducted in 1986 and 1987, was continued eastward during 1988 to include the South River (NTS 31 E/14) and Burk's Falls (NTS 31 E/11) map sheets (scale 1:50 000) (Figure 65.1). Highway 11, parts of Highways 124, 518, 520, and 522, and an extensive township and cottage road network, provide the major access to the western part of the map area. Access to the eastern part of the area is limited to a few cottage roads, Algonquin Provincial Park access roads, and logging trails. The larger lakes and rivers in the area were traversed by canoe. The access reflects the physiography of the study area: strongly bedrock-controlled uplands in the eastern part, and a broad, gently rolling plain in the western part.

Previous Quaternary mapping of the area is primarily of a reconnaissance nature (Chapman 1975; Chapman and Putnam 1984; Mollard 1981). Many studies of the glacial history of the Lake Huron basin also apply indirectly to the study area (e.g. Kaszycki 1985, 1987; Vincent *et al.* 1987; Noble and Phillips 1988). Adjacent areas which have been mapped in detail are to the southwest and west (Kor 1986, 1987), to the east in Algonquin Provincial Park (Ford and Geddes 1986), and to the north (Harrison 1972). Studies of the Huron basin shorelines within the study area include those by Goldthwait (1910), Antevs (1925), Harrison (1972), and Larson (1985, 1986).

BEDROCK GEOLOGY

The study area is underlain predominantly by foliated, gneissic, and migmatitic complexes of the Grenville Province of the Canadian Shield (Wynne-Edwards 1972). The weakly structured Powassan Batholith, a metaplutonic body of quartz monzonite to monzonite composition, occupies the western part of the South River map sheet (Davidson and Mor-

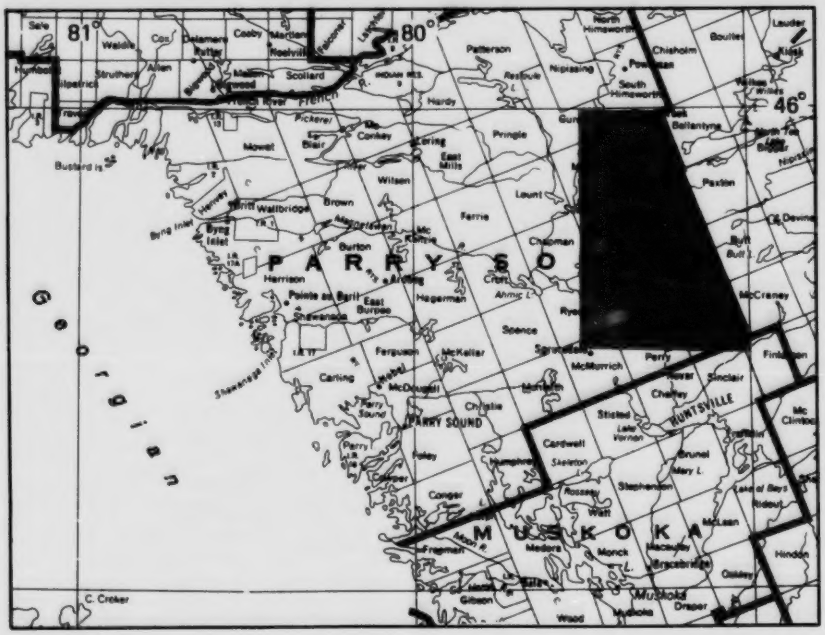

Figure 65.1. *Location map for the Sundridge-Burk's Falls Area, Central Ontario. Scale: 1:1 584 000 or 1 inch to 25 miles.*

gan 1980). All rocks in the area are of Precambrian age.

QUATERNARY GEOLOGY

The direction of the last (Late Wisconsinan) glacial advance over the region is south–southwesterly. Ice-flow indicators, primarily striations, range between 146° and 222° azimuth, with the majority ranging between 170° and 190° azimuth. The present map area was deglaciated about 11 500 B.P. (Before Present), at which time the western part of the area was inundated by an expanding glacial Lake Algonquin. Veillette (1986) suggested that the Laurentide Ice Sheet was subdivided into two lobes upon deglaciation, with a major north–south suture zone along the present Highway 11 corridor. Great volumes of ice-contact and glaciofluvial sediments were deposited in this suture zone. These were subsequently partly buried by glaciolacustrine sediments deposited in glacial Lake Algonquin and post–Algonquin phases.

As deglaciation of the uplands to the east progressed, Harrison (1972) proposed that the first eastern outlet of glacial Lake Algonquin opened up through the study area. The South River outlet is thought to have flowed north and east through the Smyth Creek valley, Kawawaymog Lake, Amable du Fond River to North Tea Lake and beyond to the Petawawa River. Further ice retreat opened the Genesee outlet, in part diverting flow west of Kawawaymog Lake northward, through Genesee Lake to the Upper Petawawa River. The present study and observations made by Ford and Geddes (1986) suggest that fluvial activity through these systems was not as great as would be required by Harrisons's hypothesis. It is probable that eastward drainage of the lake commenced once the ice retreated north of the Trout Creek area. Subsequent eastward drainage through the Fossmill and North Bay areas had the effect of lowering the lake, and may account for the topographically lower deltaic and glaciolacustrine deposits north of Sundridge. Southern outlets subsequently lowered the lake rapidly to the Hough Phase, exposing the entire map area for the first time. Continued uplift and erosion produced the present landscape.

The distribution and thickness of glacial drift in the study area varies greatly. Generally, the eastern part of the map area, and all areas above 405 m (1250 foot) contour, consist of extensive bedrock-drift complex and areas of thick (>1 m) till. The till in these areas generally does not mask the underlying bedrock topography, though extensive rock exposure is not common. The western parts of the area are underlain by thick sequences of ice–contact stratified drift and glaciolacustrine sediments which effectively mask the character of the bedrock.

Till is the dominant deposit on the bedrock–controlled uplands. A single till sheet with two distinct facies is recognized. The dominant facies is bluish–grey, loose, stony (10 to 30 percent clasts by volume) and has a sandy matrix. Sandy lenses and stringers occur throughout this till facies, particularly in association with larger clasts and at the drift–rock interface. Occasionally, a more compact, clast–poor (<10 percent), slightly fissile till facies was observed to occur on the stoss (up–ice) sides of bedrock walls. Bullet–shaped clasts and stringers of sorted sands are common in this facies. The till is considered to have formed under conditions of stagnating ice by basal meltout. The tills are commonly deeply weathered. Supraglacial and flow till facies are also present in the study area and form a minor component of the till sheet.

Ice–contact deposits occur in abundance in bedrock–controlled valleys through the eastern uplands, and below glaciolacustrine sediments in the low–lying areas in the western parts of the study area. Kames occur sporadically as individual mounds and as complexes, particularly between Highway 11 and the eastern uplands north of Bernard Lake. In the bedrock valley sites, kames are commonly associated with eskers. The eskers are generally short, narrow, steep–sided ridges in braided patterns with intervening kettles. The eskers usually protrude from kettled outwash deposits, and are composed of gravelly sands with a very high boulder content. Undifferentiated ice–contact deposits are common on the leeside of bedrock scarps. These deposits are composed of poorly sorted to crudely bedded sands and gravels of highly variable texture with an abundance of boulders.

Ice–contact subaquatic outwash fan deposits, usually overlain by deltaic sand and gravel, were identified in a number of lowland depressions along the Highway 11 corridor. The sediments consist of laminated silts, sands, and fine gravels, commonly deformed by loading and dewatering, with associated massive sand and diamict flows. They are believed to have been deposited subglacially or near the ice margin by glacial meltwaters exiting into glacial Lake Algonquin. Subsequent drainage of surface meltwaters into Algonquin and post–Algonquin lake phases resulted in the deposition of the overlying deltaic sand and gravel. The subaquatic outwash fan deposits may be quite extensive beneath the glaciolacustrine cover, but the lack of topographic and tonal expression of these deposits on airphotographs makes it difficult to determine their exact extent.

Glaciofluvial outwash deposits, predominantly sand and gravel, occur in abundance along the bedrock valley systems throughout the eastern uplands. Braided outwash also occurs across the deltaic deposits in the lower areas to the west of the highlands. The flat upper surfaces of these deposits are occasionally kettled. The glaciofluvial outwash deposits represent meltwater channels active after glacial lake levels dropped from their high phases.

Along the Highway 11 corridor, the predominant deposits consist of sand and fine gravel of glaciolacustrine origin, often in the form of large flat plains. These are commonly confined by bedrock uplands. Sections within deltaic deposits exhibit planar laminated, ripple to cross-bedded sand and fine gravel, usually flat lying to gently dipping to the south and southwest. The upper surfaces of these deposits generally lie below expected Main Algonquin uplift curve elevations, and are therefore interpreted to represent post-Algonquin levels. The paucity of raised shoreline features cut into the glaciolacustrine deposits is attributed to the ice forming the shore of glacial Lake Algonquin at the time of deposition of these deposits.

Glaciolacustrine fine-grained deposits, predominantly grey silt and red clay rhythmites, occur sporadically in the low-lying areas of the western part of the study area. They are locally abundant and may be up to 4 m thick. While Antevs (1925) noted up to 18 m of sediment containing over 300 couplets in composite sections near Trout Creek and South River, the present study only noted slightly more than 100 couplets at any one site. The rhythmic sequences commonly grade upward to a greyish-red, massive, blocky-textured silt-clay. These fine-grained sediments are commonly folded and faulted and are overlain by sand and fine gravel. The silts and clays represent distal and quiescent lake conditions during relatively stable lake phases in the post-Algonquin basin. Sand and gravel was deposited in shallow water conditions as the lake dropped to lower levels.

Extensive alluvial deposits along rivers and creeks represent reworking of the glacial substrate by post-glacial rivers. Large tracts of organic terrain occur on the lowlands and occupy innumerable bedrock depressions in the uplands. Modern beaches occur where sufficient material exists on windward lakeshores to allow the reworking of the sediment.

ECONOMIC GEOLOGY

A number of large sand and gravel operations exploit the ice-contact stratified drift and glaciolacustrine stratified sediments along the Highway 11 corridor. It is expected that in the short term, these deposits will produce adequate volumes of aggregate to meet local needs. The ice-contact sediments are frequently too variable in texture to be economically significant, although they are utilized locally east of Highway 11. Till and outwash deposits are also used in the uplands east of Highway 11 for local road construction and landfill.

Cal Graphite Limited is setting up an open pit graphite operation near Graphite Lake in Butt Township (Garland 1987). It has been reported that aggregates south of this deposit contain enough graphite to restrict its use.

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66. Project Number 86–20. Quaternary Geology of the Shining Tree Area, Districts of Sudbury and Timiskaming

P.W. Alcock

Geologist, Engineering and Terrain Geology Section, Ontario Geological Survey, Toronto.

INTRODUCTION

The study area is bounded by Latitudes 47°30′N and 48°00′N and Longitudes 81°00′W and 81°30′W (Figure 66.1). It includes two 1:50 000 scale map sheets: Shining Tree (NTS 41 P/11) and Sinclair Lake (NTS 41 P/14).

The objectives of this project are to determine the distribution and stratigraphy of the Quaternary sediments and to expand the geological database of the area for mineral exploration, forestry, and land use planning.

Quaternary geological mapping at a scale of 1:50 000, reconnaissance surficial till sampling, and overburden trenching have been undertaken in the Shining Tree map area by Finamore (1986) and in the Sinclair Lake map area by the author in 1987 (Alcock 1987) and 1988. Airphoto interpretation, map compilation, and analysis of data are currently in progress.

QUATERNARY GEOLOGY

The area investigated contains a surficial sedimentary sequence representing the last major, late Wisconsinan ice advance, and postglacial lake and eolian activity. Glacially streamlined and striated bedrock outcrops, till fabrics, and dispersion trends of lithologic indicators demonstrate that the last dominant ice movement in the study area was towards 180±30° azimuth in the study area. Minor late–glacial shifts in ice direction due to bedrock topographic influences are indicated by a few examples of 160° to 180° striations cross–cutting an earlier set of 140° to 160° striations. Certain roches moutonees preserve facets or remnants of grooves oriented southwest–northeast on their lee sides. On rare outcrops, southwesterly oriented striations are crossed by southwards oriented ones. This evidence suggests an earlier ice advance to the southwest, similar to that documented by Veillette (1986) in the Timmins, Matheson, and Lake Temiskaming areas.

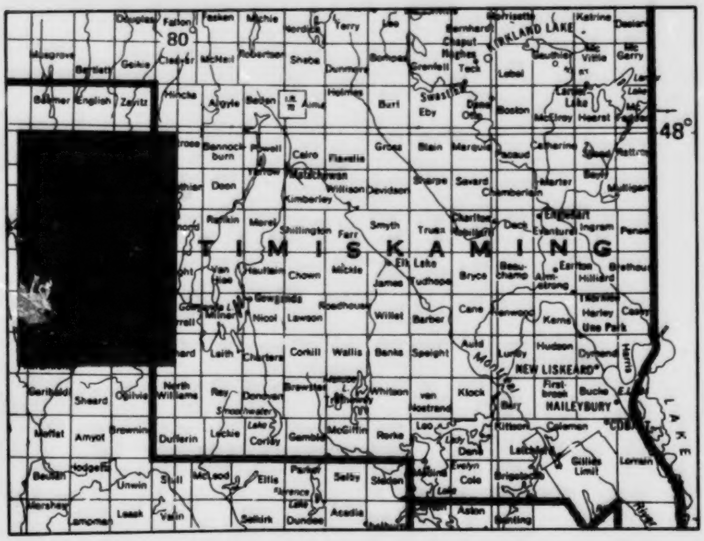

Figure 66.1. *Location map for the Shining Tree Area. Scale: 1:1 584 000 or 1 inch to 25 miles.*

CANADA ONTARIO

This project A.4.1 is part of the five year Canada–Ontario 1985 Mineral Development Agreement (COMDA), a subsidiary agreement to the Economic and Regional Development Agreement (ERDA) signed by the governments of Canada and Ontario.

Drift thicknesses in the study area range from less than 1 m to more than 50 m.

Only rare carbonate lithology clasts have been found in the study area, usually in glaciofluvial deposits. This indicates the area is south and east of the limit of carbonate drift as mapped by Karrow and Geddes (1987).

One till sheet was found over the study area, which usually forms a veneer (<1m) over bedrock but ranges up to 4 m or more in thickness. Both subglacial and supraglacial till facies were identified using sedimentological and structural characteristics. All till at surface has been affected by soil forming processes, oxidation, and translocation of matrix carbonate to a depth of at least 1 to 2 m.

Subglacially deposited till facies are common at or near surface in areas of till veneers over bedrock and in areas of thick till. The melt–out till facies appears as loose to moderately compact till with thin sorted and deformed sand bands, commonly grading down into a compact lodgement till facies which in turn overlies striated bedrock. The lodgement facies commonly has a higher content of fines and a higher percentage of local rock types than the melt–out facies. The composition of subglacially deposited till facies often strongly reflects local bedrock.

The supraglacially deposited till facies are found as thin units overlying subglacially deposited facies. Flow till facies are often found on or between bedrock knobs and consist of moderately to loosely compacted sandy till with some glacially faceted and striated clasts, sorted sand stringers, and crude banding or layering of flow units. Ablation till facies are commonly thin, loose, sandy tills with frequent subrounded exotic cobbles and boulders. These supraglacial till types often poorly reflect the local bedrock.

Glaciofluvial ice–contact deposits consist of cobbly to bouldery sand and gravel and occur as segmented and beaded eskers, kames, and other stagnant ice features. In the major valleys and in the broad, bedrock–controlled topographic lows, large, discontinuous and occasionally compound esker complexes are often present. Locally, small kames are found in valley bottoms among drift–veneered bedrock knobs.

Glaciofluvial outwash deposits, consisting of pebbly to gravelly sand, flank the esker systems. Occasionally, fans of outwash sediments are found at the downstream end of esker segments. Extensive tracts of kettled and occasionally terraced outwash occupy large sections of the southeastern portion of the Shining Tree map area and the north and central parts of the Sinclair Lake map area. Minor glaciofluvial deposits occur in local valleys.

Glaciolacustrine deposits, consisting of rhythmically laminated to massive silt, fine sand and occasional clay, occupy broad lows and the margins of the major north–south valleys. These deposits are exposed along the shores of Kapiskong, Sinclair, Marne, and Mattagami lakes and are locally up to 15 m in thickness. Thin but extensive glaciolacustrine deposits occupy the sites of former shallow proglacial lakes near Granite Lake and Shining Tree Lake in the Shining Tree map area and near Burrows, Halliday, Relic, and Seveninch lakes in the Sinclair Lake map area. No definite shoreline features have been identified from these glacial lakes, suggesting they were quite shortlived.

Eolian deposits consist of well sorted, finely laminated coarse silt to fine sand and form dunes and a widespread, thin surficial veneer over bedrock–drift complex, till, and glaciofluvial deposits. Parabolic and longitudinal sand dunes up to 20 m in height are common. Dune fields occur near Nabakwasi Lake, Waonga Lake, and Claw Lake in the Shining Tree map area and near Loonwing Lake, Bardwell Lake, the Grassy River, Edleston Lake, and Jumping Moose Lake in the Sinclair Lake map area. Dune fields are located on and down–paleowind direction (southeast) from parent deposits of fine–grained glaciofluvial outwash and glaciolacustrine sands.

Recent alluvial deposits consist of sand, silt, gravel and some organic material and are found along those larger watercourses which cut through glaciofluvial deposits. Alluvial deposits are present along the Donnegana River and West Montreal River in the Shining Tree map area and the Grassy River in the Sinclair Lake map area. Most deposits are of very restricted areal extent and thickness.

Deposits of peat and muck up to a few metres in thickness are found in bogs and swamps occupying local topographic depressions and along the meandering streams and rivers. Thin organic deposits occur over extensive areas on glaciolacustrine sand plains.

APPLIED QUATERNARY GEOLOGY

A reconnaissance till sampling program has been carried out to create a geochemical database and determine how overburden sampling can be effectively used as a mineral exploration technique in the study area. A total of 170 samples of weathered surface till were collected and geochemical analyses performed for Ag, As, Au, Ba, Co, Cr, Cu, Fe, Li, Mn, Mo, Ni, Pb, Pd, Pt, Sb, and Zn. A total of 137 samples of weathered and unweathered till were collected for heavy mineral concentrate (S.G. greater than 3.3) preparation, gold grain counts, and heavy mineral grain counts. Statistical analysis of the data is in progress.

Preliminary results indicate that boulder tracing, surface till sampling, and backhoe trenching are effective exploration methods in those areas with till at or near surface. Traditional soil geochemical sampling would not be effective in those areas where non-local glaciolacustrine or eolian sand forms the soil parent material.

RELATED RESEARCH

J.T. Aultman (1988) completed a B.Sc. honours thesis at the University of Western Ontario on the nature of gold dispersal in till in the Shining Tree area. Results from surface till samples collected up to several hundred metres down-ice of known gold occurrences indicate gold grains are present in the sand-sized heavy mineral fraction. Further work has also indicated anomalous gold geochemical values in the silt and clay fraction of these samples.

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67. Project Number 86–21. Quaternary Geology and Overburden Exploration in the Beardmore–Geraldton–Longlac Area, District of Thunder Bay

F.J. Kristjansson

Geologist, Engineering and Terrain Geology Section, Ontario Geological Survey, Toronto.

INTRODUCTION

During the 1986 and 1987 field seasons, a joint Ontario Geological Survey and Geological Survey of Canada project of Quaternary geological mapping (Kristjansson and Thorleifson 1987) and regional till sampling (Thorleifson and Kristjansson 1987) was conducted in the Beardmore–Geraldton–Longlac area (Figure 67.1). The primary purpose of the project was to provide a data base which would facilitate programs of drift prospecting.

Because till represents a prime geochemical sampling medium for overburden exploration in areas of glaciated terrain, the objectives of the project were to assess: 1) till stratigraphy, sedimentology, and composition; and 2) the direction of glacier flow in the study area, and relationships to till stratigraphy.

QUATERNARY GEOLOGY

TILL STRATIGRAPHY, SEDIMENTOLOGY, AND COMPOSITION

A local, lodgement till, which in general occurs as a thin, discontinuous sheet immediately overlying bedrock, represents the earliest till deposition in the study area. An abundance of clasts exhibiting striations, facets, and stoss and lee features, and the presence of glaciotectonic structures suggest that deposition by lodgement processes prevailed during accretion of this till. This till type was encountered frequently at the surface in bedrock–controlled terrain associated with a thin till cover, and commonly at the base of boreholes in areas of thick till cover (Thorleifson and Kristjansson 1988).

The till can be quite compact and, in section, often exhibits a weak to well–developed fissile structure. Texturally, local, lodgement till varies from a

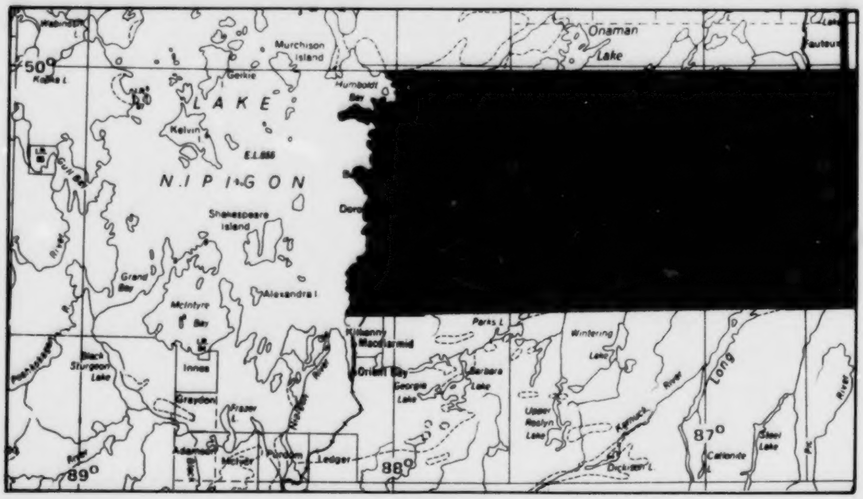
Murchison Island
Onaman Lake
Fauteux
50°
Geikie
Humboldt Bay
LAKE
NIPIGON
Kelvin I.
Gull Bay
Shakespeare Island
Grand Bay
Alexandra I
McIntyre Bay
Innes
Black Sturgeon Lake
Graydon
Fraser L.
Nipigon
Macdiarmid
Orient Bay
Georgia Lake
Barbara Lake
Parks L.
Wintering Lake
Upper Roslyn Lake
Kenogami River
Long
Dickison L.
87°
Caramat
Steel Lake
Pic River
Adamson
McIvor
Purdom
Ledger
88°
89°
River

Figure 67.1. *Location map for the Beardmore–Geraldton–Longlac area, District of Thunder Bay. Scale: 1:1 584 000 or 1 inch to 25 miles.*

This project A.5.4 is part of the five year Canada–Ontario 1985 Mineral Development Agreement (COMDA), a subsidiary agreement to the Economic and Regional Development Agreement (ERDA) signed by the governments of Canada and Ontario.

moderately clast–rich, clayey silt to a clast–rich, silty sand. Textural variation would appear to be related to the lithologies present in the source area. For example, local, gritty, clayey silt till would reflect derivation from a source area dominated by pelitic metasedimentary rocks. Local, gritty, silty sand till reflects a source area dominated by metavolcanic or arenaceous metasedimentary rocks. The clast composition of this till variety is dominated by rock types of local provenance. A high percentage of angular–subangular Archean greenstone clasts is characteristic. Many of the heavy mineral concentrates derived from samples of this particular till contained visible gold grains.

Nonlocal, carbonate–rich till overlies both bedrock and local, lodgement till. Generally, deposits of this till variety are thick and laterally extensive, particularly in the central part of the study area. A lower, gritty, silt facies and an upper, gritty, sandy silt facies have been defined.

The lower facies is extremely compact and, in section, exhibits a blocky to fissile fracture. The ubiquitous presence of clasts exhibiting striations, facets, and stoss and lee features; the presence of boulder pavements; and the presence of glaciotectonic structures suggest that the lower, gritty, silt facies was deposited predominantly through lodgement processes under dynamic ice conditions.

The upper facies is loose to moderately compact. In section, massive, diamictic zones were often observed in association with stringers, lenses, and other variously shaped units of sand. It is suggested that this phase of the nonlocal, carbonate–rich till was deposited predominantly through melt–out processes.

The lithologic composition of nonlocal, carbonate–rich till is dominated by an abundance of subrounded pebbles and occasional cobbles of Proterozoic and Paleozoic clastic and chemical sedimentary rocks derived from the James Bay and Hudson Bay lowlands. Generally, heavy mineral concentrates derived from samples of this exotic till variety did not contain visible gold grains.

A local, melt–out till occurs as a thin, discontinuous veneer overlying bedrock or nonlocal, carbonate–rich till. This till variety was observed in the southern part of the study area, which is underlain by bedrock of the Quetico Metasedimentary–Migmatitic Belt, and in an area underlain predominantly by felsic plutonic bedrock north and northwest of Geraldton. There appears to be a strong spatial relationship between the presence of local, melt–out till and bedrock–dominated upland areas. To date, the author has not observed this till type within those parts of the study area underlain by the Onaman–Tashota Belt and the Beardmore–Geraldton Belt.

In summary, and in stratigraphic order, four varieties of till were observed in the Beardmore–Geraldton–Longlac area: 1) local, lodgement till; 2) nonlocal, lodgement till; 3) nonlocal, melt–out till; and 4) local, melt–out till.

GLACIAL FLOW AND TILL STRATIGRAPHY

Glacial striae, glacier–streamlined bedrock forms and drumlins indicate an early glacial advance to the south and a more recent glacial advance to the southwest. Evidence of the early advance are rare, planar, erosional bedrock facets with striations ranging from about 190° in the Geraldton area to about 210° in the Beardmore area. Ice direction features of the most recent advance indicate a diverging or radial flow pattern. Generally, ice flow indicators examined in the eastern, central, and western parts of the study area trend about 200° to 220°, 220° to 240°, and 240° to 260°, respectively.

On the basis of the trend of striations on bedrock pavements underlying local, lodgement till; the trend of striations on boulder pavements observed within sequences of nonlocal, carbonate–rich till; and the orientation of drumlins composed of nonlocal, carbonate–rich till, it is considered that the entire till sequence was deposited during the later episode of glacier flow. The possibility that some occurrences of local, lodgement till, at the base of boreholes in areas of thick till cover, are representative of the early episode or even an undocumented episode of glacier flow should not be dismissed.

SUMMARY AND CONCLUSION

1. Local, lodgement till represents the prime sampling horizon for till geochemistry programs. The fact that this till type was encountered frequently in thin till/bedrock terrain, and commonly at the base of boreholes in thick till terrain, suggests that there has been substantial glacier dispersion of local bedrock. More importantly, such observations indicate that there has been good preservation of this till variety.
2. Nonlocal, carbonate–rich till, due to its obvious distant–source composition, represents a constraining factor with respect to till geochemistry programs.
3. Surface till and soil sampling represent viable overburden exploration strategies in areas of thin till/bedrock terrain. This is especially the case in the area of the Beardmore–North Wind Lake map sheet.
4. Overburden drilling is required in areas of thick till terrain. A thick and widespread till sheet overlies a substantial portion of the Beardmore–Geraldton Belt. The till sheet has proved to be a distinct impediment to conventional programs of mineral exploration. A program of reverse circulation or sonic drilling is recommended for this area.
5. The importance of accurate till identification cannot be over–emphasized.

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68. Project Number 86–22. Reconnaissance Till Sampling in the Fort Frances–Rainy River Area, Rainy River District

A.F. Bajc

Geologist, Engineering and Terrain Geology Section, Ontario Geological Survey, Toronto.

INTRODUCTION

After completion of regional Quaternary mapping in the Fort Frances–Rainy River area, a follow–up program of till sampling was undertaken during the 1988 field season. This program consisted of rotasonic overburden drilling, backhoe trenching, and hand–dug testpitting, with detailed sampling and section descriptions. This work completes a three–year field program which was initiated during the 1986 field season. The aims of the project are two–fold. Firstly, to establish a framework of Quaternary geology for mineral exploration and secondly, to generate a geochemical data base for this largely unexplored area. A thick cover of overburden over much of the study area, which is underlain by Archean supracrustal rocks of the Western Wabigoon Subprovince, has hindered mineral exploration programs. The information produced by this program will provide guidelines for future mineral exploration programs, as well as outline areas with mineral potential.

The study area is approximately 3500 km^2 in area and is bounded by the 49th parallel of latitude to the north and the Rainy River to the south. Lake of the Woods and Rainy Lake form the western and eastern borders, respectively (Figure 68.1).

Detailed mapping of the western half of the study area (Rainy River Area) was undertaken during the summers of 1986 (Bajc and Gray 1987). Mapping of the eastern half (Emo and Northwest Bay Area) was completed during the summer of 1987 (Bajc and White, in preparation; Bajc, White, and Gray, in preparation). The first phase of a rotasonic overburden drilling program was completed during the fall of 1987. A summary of Quaternary field work and findings within the study area is given in the Ontario Geological Survey 1987 Summary of Field Work and Other Activities (Bajc 1987).

QUATERNARY HISTORY

The study area was affected by two phases of glaciation during the Late Wisconsinan. An initial, strong

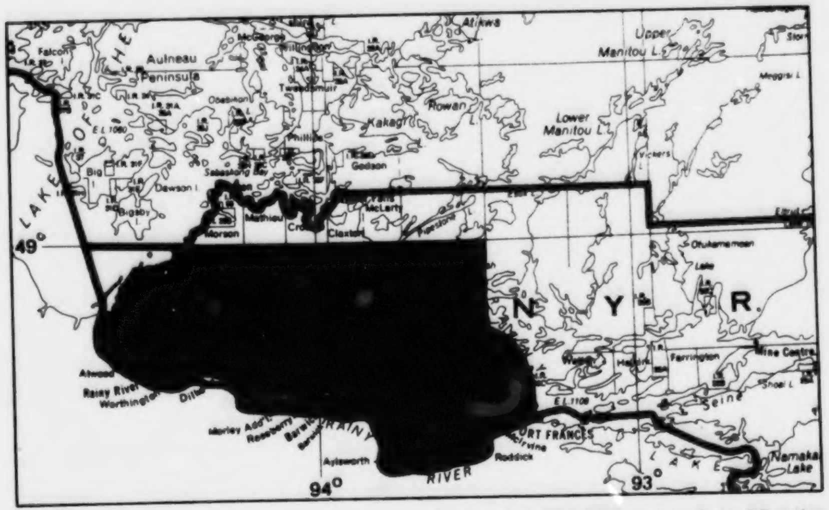
Aulneau Peninsula
Falcon I.
LAKE OF THE
Big I.
Bigsby I.
Dawson I.
Obabikon
Tweedsmuir
Phillips
Kakagi
Rowan L.
Atikwa
Upper Manitou L.
Lower Manitou L.
Meggisi L.
Vickers
Godson
Sabaskong Bay
Morson
Mathieu
Claxton
McLarty
Pipestone L.
Otukamamoan Lake
N Y R.
Atwood
Rainy River
Worthington
Dilke
Morley
Roseberry
Barwick
Aylsworth
RAINY RIVER
FORT FRANCES
Irvine
Roddick
Ferrington
Mine Centre
Shoal L.
Seine
LAKE
Namakan Lake
49°
94°
93°
LOCATION MAP
Scale: 1:1 584 000 or 1 inch to 25 miles

Figure 68.1. *Location map for reconnaissance till sampling in the Fort Frances–Rainy River area, District of Rainy River. Scale: 1:1 584 000 or 1 inch to 25 miles.*

CANADA ONTARIO

This project A.6.5 is part of the five year Canada-Ontario 1985 Mineral Development Agreement (COMDA), a subsidiary agreement to the Economic and Regional Development Agreement (ERDA) signed by the governments of Canada and Ontario.

advance from the northeast was followed by a late glacial surge from the west prior to deglaciation about 11 500 years B.P. Glacial Lake Agassiz fronted the advancing and retreating ice masses over much of the area. Deposits of the older advance are found at the surface in the northeastern corner of the study area and are buried by deposits of the next ice advance over much of the remaining parts of the map area. The older, lower glacial (northeastern origin) package consists of a stoney, silty sand till of variable thickness and low matrix carbonate overlain by glaciofluvial sand and gravel and/or glaciolacustrine sand, silt, and minor clay. The upper glacial package (western origin) consists of a stone-poor silty very fine sand to silty clay till with high matrix carbonate. This till is overlain, underlain, or interbedded with glaciolacustrine silt and clay and/or glaciofluvial sand and gravel. Pebbles recovered from the lower northeastern-derived till sheet suggest a local to semi-local source, whereas the upper till contains lithologies derived predominantly from south-central Manitoba. The lower till is recommended as the prime sampling medium for a drift prospecting program because of its local to semi-local provenance.

TILL SAMPLING STRATEGIES

Three till sampling techniques were utilized in the Fort Frances-Rainy River area. These include: 1) rotasonic overburden drilling; 2) backhoe trenching; and 3) hand-dug testpitting. The method used depended upon several factors, namely: 1) depth below surface of the lower, older till sheet; 2) the abundance of bedrock outcrop; and 3) road accessibility. The study area can be subdivided into three discrete zones where one or more of the above mentioned sampling techniques can be used (Figure 70.2). Road access into the extreme northeastern corner of the map area (Zone 1), where the drift is thin and discontinuous (>80 percent bedrock outcrop) is limited. The older, northeastern-derived till sheet, however, is found on surface in this area and can easily be sampled to a depth of 1.5 m using hand-dug testpitting. Bedrock outcrops become less common to the southwest due to a thickening, more extensive drift cover. A second zone defined by moderately abundant bedrock outcrop (30 to 40 percent by area) and localized pockets of thick drift (Zone 2) is outlined in Figure 70.2. The lower till unit is buried beneath younger clay-rich sediments in this area and rises up to the surface around most bedrock outcrops. It is in these areas that backhoe trenching adjacent to bedrock outcrops is most cost effective and time efficient for intersecting and sampling the lower till unit. Overburden thicknesses of 20 to 30 m may also occur in this zone, thus, justifying the use of a reverse circulation or rotasonic overburden drill as a secondary means of obtaining large samples of the lower till. A third zone (Zone 3) is

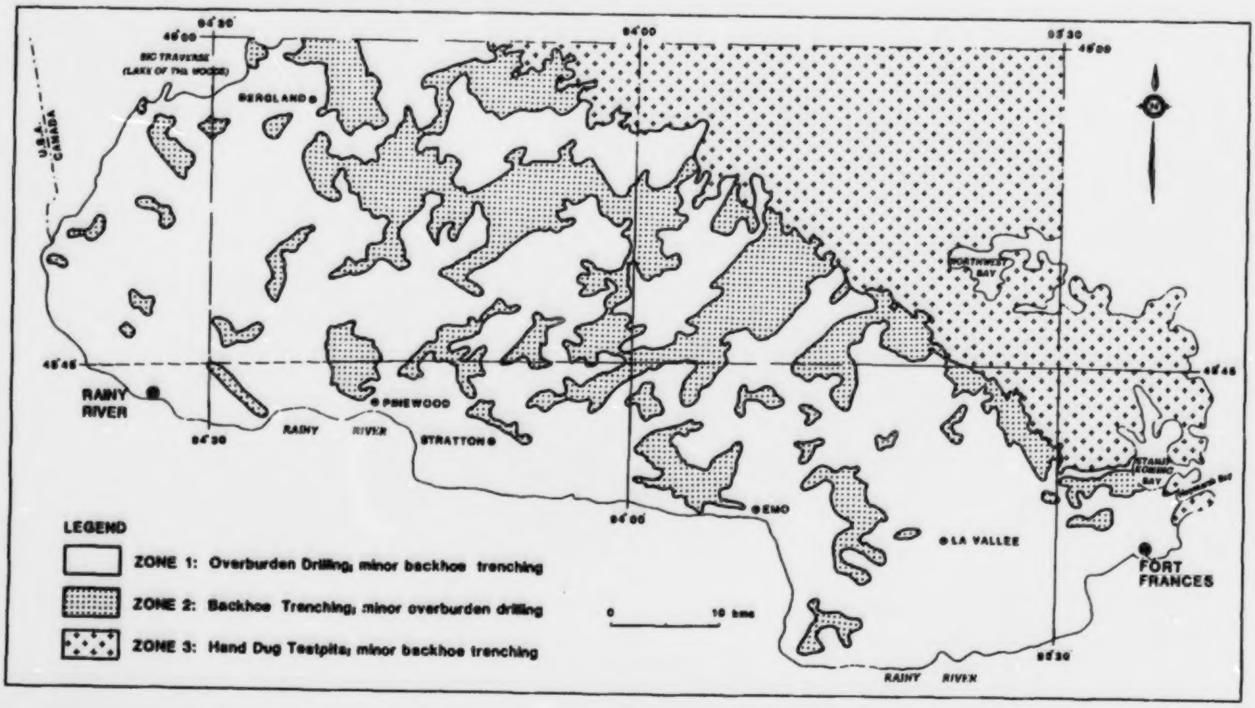
94°30'
49°00'
94°00'
93°30'
49°00'
BIG TRAVERSE
(LAKE OF THE WOODS)
BERGLAND
U.S.A.
CANADA
NORTHWEST BAY
48°45'
48°45'
RAINY RIVER
PINEWOOD
94°30'
RAINY RIVER
STRATTON
EMO
94°00'
LA VALLEE
STANJIKOMING BAY
FORT FRANCES
93°30'
RAINY RIVER
0
10 kms
LEGEND
ZONE 1: Overburden Drilling; minor backhoe trenching
ZONE 2: Backhoe Trenching; minor overburden drilling
ZONE 3: Hand Dug Testpits; minor backhoe trenching

Figure 70.2. *Zones in the Fort Frances-Rainy River area within which different overburden exploration techniques can be used.*

characterized by sporadic outcrops (<5 percent by area) and overburden thicknesses commonly in excess of 30 m, and occasionally up to 60 m. This zone is present along the modern course of the Rainy River and occupies large, extensive tracts in the extreme western and southeastern parts of the map area. Less extensive and irregular areas of Zone 3 are found within the central part of the map area. It is within Zone 3 that deep overburden drilling techniques, such as rotasonic and reverse circulation, are necessary. Backhoe trenching adjacent to the widely scattered bedrock outcrops of Zone 3 is also a useful means of obtaining additional samples of the lower till.

SUMMARY OF THE 1987 AND 1988 SONIC DRILLING PROGRAMS

During the fall of 1987, a 16–day rotasonic drilling program was undertaken during which 34 continuously cored boreholes were completed. This drilling yielded relatively undisturbed cores, 9 cm in diameter. Nearly 1060 m of overburden and 70 m of bedrock core were recovered from the drilling program. Refer to Table 68.1 for a summary of drilling statistics. A total of 28 of the 34 boreholes intersected the lower till. The thickest accumulations of the lower till are 17 m in the western end of the study area and approximately 3.5 m in the eastern end.

The second phase of drilling was undertaken during the fall of 1988 with 37 boreholes completed over a period of 25 days. There was 996 m of overburden and 77 m of bedrock core recovered from the drilling program. Table 68.1 summarizes pertinent drill program information. A total of 36 of the 37 boreholes intersected the lower, northeastern–derived till. The thickest accumulations of this till are approximately 22 m in the western end of the study area and 9 m in the eastern end.

TABLE 68.1. SUMMARY OF 1987 AND 1988 SONIC DRILLING PROGRAMS.

	1987	1988
Number of hours drilled	156.75	214.25
Number of holes drilled	34	37
Average number of holes per 12–hour shift (including drilling, moving, and down time)	2.1	1.5
Metres drilled per hour	7.2	5.0
Total overburden drilled (m)	1058.9	995.7
Average overburden thickness per hole (m)	31.1	26.9
Total bedrock drilled	69.2	76.5
Average bedrock drilled per hole (m)	2.0	2.1
Percentage of holes upper till encountered	100	92
Percentage of holes lower till encountered	82	97

SUMMARY OF 1988 BACKHOE TRENCHING PROGRAM

A 10–day backhoe trenching program was undertaken during the past field season on road allowances adjacent to bedrock outcrops. A total of 37 trenches were dug in the area outlined by Zone 2 of Figure 68.2 and 7 trenches in Zone 1. Samples of the older, locally derived till were obtained from all of the trenches dug in Zone 1 and 27 of the 37 trenches dug in Zone 2. Of the 37 trenches dug in Zone 2, 8 were placed on the northern, 9 on the southern, 12 on the eastern, and 8 on the western sides of the bedrock outcrops. There does not appear to be a side along which the lower till is preferentially preserved. However, the till appears to be looser and contains more stringers and lenses of stratified sediment on the southern and western sides of the bedrock outcrops. Tills recovered from these sides have been interpreted primarily as leeside till derived from subglacial meltout of debris. Tills recovered from the northern and eastern sides of the bedrock outcrops are denser, fissile, appear more massive, and display structures suggestive of deposition by grounded, active ice. Shear planes and extension fractures indicating southwesterly ice flow were noted in several exposures of till on the northern and eastern sides of bedrock outcrops. Pebble counts on the >5.6 mm (+4 mesh) fraction of the till suggest a local to semi–local source for this lower till sheet. Samples of till ranging from 8 to 10 kg were taken for heavy mineral separation, gold grain counts, geochemistry, grain size, and carbonate analysis.

TILL SAMPLE INVENTORY (1986–1988)

During the summers of 1986 and 1987, 197 hand–dug surface till samples ranging from 5 to 10 kg were collected from the map area. An additional 19 surface till samples were collected in areas of higher mineral potential from hand–dug surface testpits during the past field season. As part of the 10–day backhoe trenching program undertaken during the 1988 field season, 44 till samples were collected. All testpit and backhoe samples will undergo geochemical, grain size, and carbonate analysis. The 1987 rotasonic overburden drilling program yielded 238 till samples for geochemical analysis and 216 till samples for grain size and carbonate analysis. The 1988 rotasonic overburden drilling program yielded 202 till samples for geochemical analysis and 166 till samples for grain size and carbonate analysis. All till samples collected are processed to concentrate the −10 mesh (−2 mm) heavy minerals (>3.3 S.G.) for subsequent geochemical analysis. A subsample is sieved to obtain the −250 mesh fraction which is also analyzed. Other data generated for each sample includes gold grain counts and mineralogical identifications of 100 grains from the non–magnetic heavy mineral fractions.

OTHER RELATED RESEARCH

The second phase of a Geological Survey of Canada reflection seismic program was undertaken during the summer of 1988. Six common offset profiles were run over sonic boreholes drilled during the 1987 drilling program. Holes with depths in excess of 30 m and a complex stratigraphy were chosen for the program. Three additional holes cased with 2.5 inch (outside diameter) PVC pipe during the 1987 drilling program were used as test sites for a downhole seismic program. This program is aimed at establishing seismic velocity changes down the hole and across lithological breaks.

John Halstead is undertaking a B.Sc. Thesis at Brock University and will be describing the nature of the lower, northeastern–derived till sheet at 37 selected sites along a northeast–southwest transect in the central part of the map area. Special emphasis will be placed on the physical and chemical properties of the till sheet and their relationship to provenance and mode of deposition.

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69. Project Number 82–27. An Evaluation of Airborne Radar for Quaternary Studies

V.H. Singhroy[1] **and P.J. Barnett**[2]

[1]Senior Research Engineer, Ontario Centre for Remote Sensing, Ministry of Natural Resources, Toronto.

[2]Geologist, Engineering and Terrain Geology Section, Ontario Geological Survey, Toronto.

PROJECT SUMMARY

During the spring of 1988, airborne C–HH (parallel–polarized) and X–HH, SAR (synthetic aperture radar) were flown by the Radarsat Project Office of Canada Centre for Remote Sensing on three sites in Ontario. This was done for the purpose of evaluating the capability of radar imagery for Quaternary studies. The Capreol test site (40 km by 40 km), on the northern rim of the Sudbury Basin, was imaged using a narrow swath mode of 14 to 45° depression angle. The Barrie (40 km by 30 km) and the Port Stanley (10 km by 20 km) test sites were imaged with depression angles from 16 to 90° (nadir mode) in order to evaluate the effect of soil moisture on radar backscatter (Figure 69.1). For all sites, radar data was acquired at 20 000 feet, 6 km above sea level, resulting in a spatial resolution of 6 m by 6 m.

The Capreol site was chosen because of the large variety of Quaternary sediment types present within a predominantly rock–dominated terrain, typical of vast areas of the Canadian Shield (Burwasser 1979). A large part of the area is tree covered, so the important link between materials–vegetation–radar backscatter can be examined. Photo

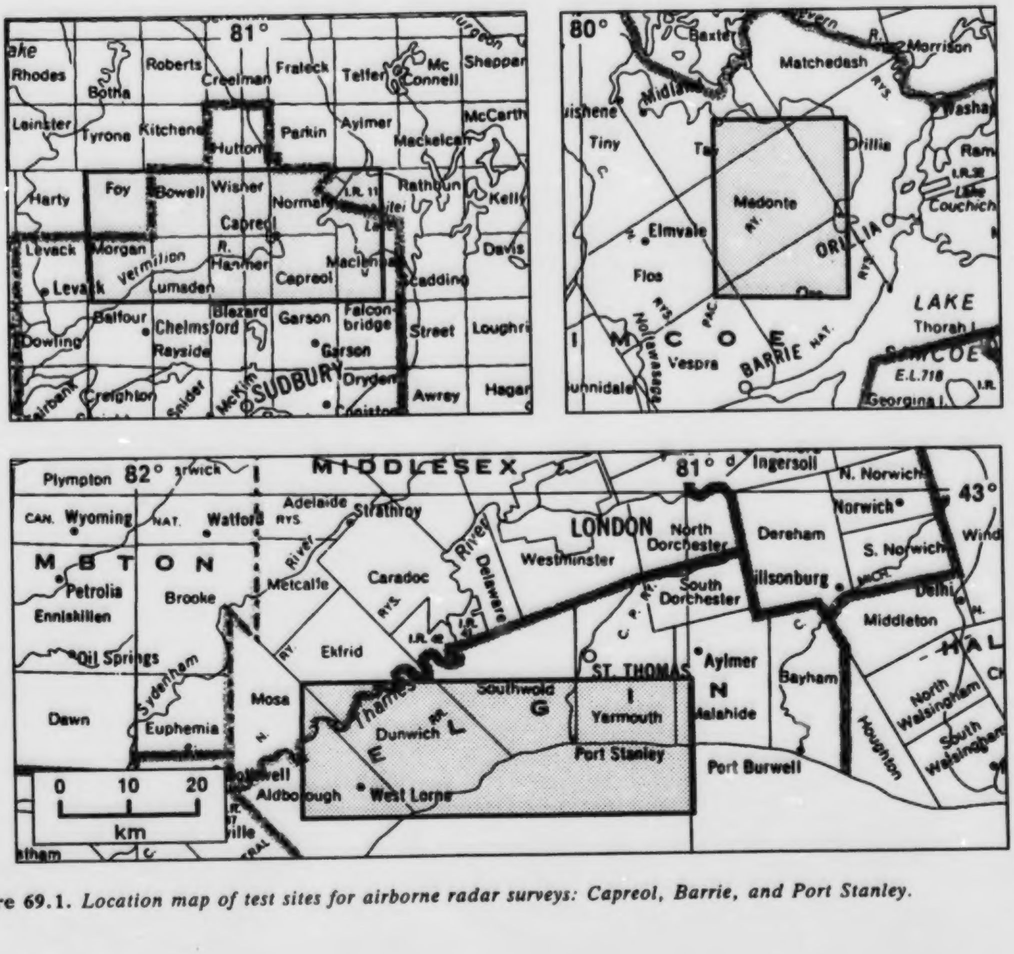
81°
Rhodes
Botha
Roberts
Creelman
Fraleck
Telfer
Mc Connell
Sheppard
Leinster
Tyrone
Kitchener
Hutton
Parkin
Aylmer
Mackelcan
McCarthy
Harty
Foy
Bowell
Wisner
Norman
Rathbun
Kelly
Capreol
Levack
Morgan
Vermilion
Hanmer
Maclennan
Davis
Lumsden
Capreol
Scadding
Balfour
Chelmsford
Blezard
Garson
Falconbridge
Street
Loughrin
Dowling
Rayside
Garson
Creighton
Snider
McKim
SUDBURY
Dryden
Awrey
Hagar
80°
Baxter
Matchedash
Morrison
Midland
Tiny
Tay
Orillia
Medonte
Elmvale
ORILLIA
Flos
LAKE
Vespra
BARRIE
Georgina I.
E.L.718
Plympton
82°
MIDDLESEX
81°
Ingersoll
43°
Wyoming
Watford
Adelaide
Strathroy
LONDON
North Dorchester
Dereham
Norwich
Westminster
S. Norwich
Petrolia
Brooke
Metcalfe
Caradoc
South Dorchester
Tillsonburg
Delhi
Enniskillen
Middleton
Oil Springs
Ekfrid
ST. THOMAS
Aylmer
Sydenham
Mosa
Southwold
Yarmouth
Malahide
Bayham
North Walsingham
Dawn
Euphemia
Dunwich
Port Stanley
Port Burwell
Houghton
South Walsingham
0
10
20
km
Aldborough
West Lorne
Thames

Figure 69.1. *Location map of test sites for airborne radar surveys: Capreol, Barrie, and Port Stanley.*

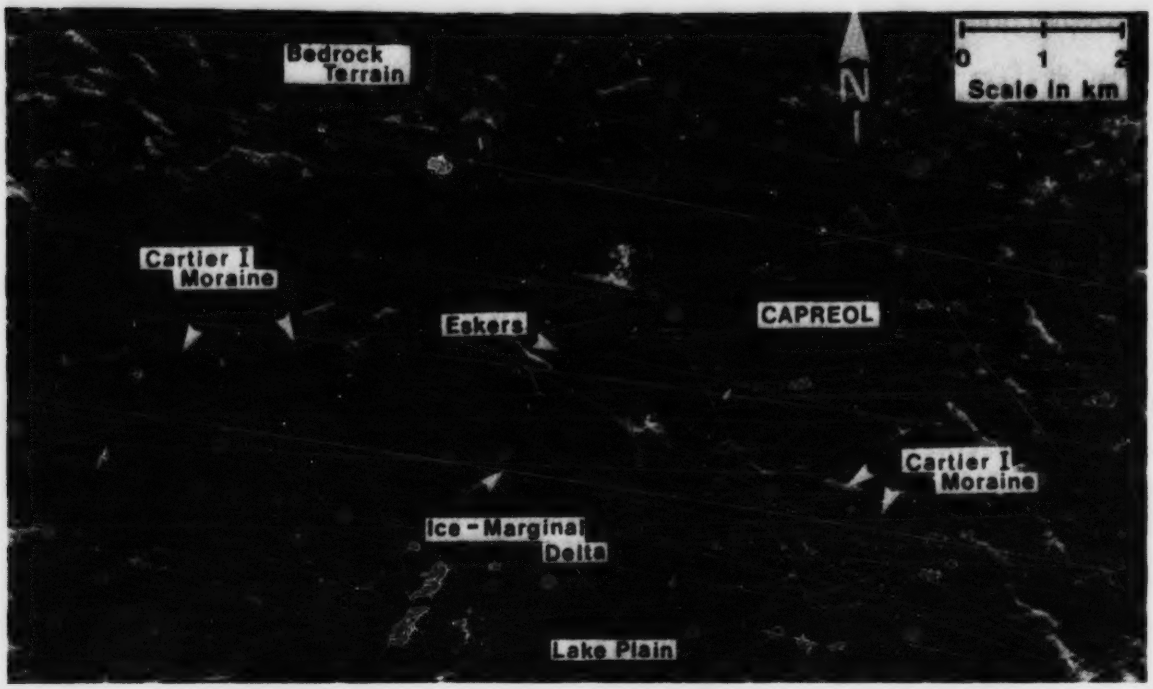

Photo 69.1. *C-HH, SAR image of the Capreol area.*

69.1 is a radar image from the Capreol test site. Bedrock structure and Quaternary landforms are well defined. An ice–marginal delta, which formed along the Cartier I Moraine (end moraine) into a high level glacial lake in the Sudbury Basin, is readily identifiable on the image. Eskers feeding the delta and downcutting into the delta top and terraces along the end moraine, formed during lower lake stages in the Sudbury Basin and are also visible on the radar image.

Variations in the thickness of glacial sediment cover are also illustrated in this image (Photo 69.1). Rock–dominated terrain with very thin and discontinuous drift cover, except along major north–south valley bottoms, occurs along the top and right–hand edge of the image area. The drift cover thickens southward and becomes more continuous immediately north of the Cartier I Moraine. The drift is very thick within the moraine, eskers, delta, and lake plain south of Capreol. In the lower–left corner of the image, rock outcrops in ridges, indicating some of the structures and layering of the bedrock within the Sudbury Basin.

At the Barrie test site, emphasis is placed on the use of radar data to provide information on regional geomorphology and material types as an aid to Quaternary geological mapping in the area (Barnett 1986; *see* Barnett, this volume). The Barrie area contains many large– and small–scale geomorphic features and radar may be useful in obtaining information on their distribution and relationships. The location and extent of ancestral glacial lake shorelines of Georgian Bay, the distribution of drumlins and stagnant ice features, and their relationships to the large tunnel valleys in the area is being examined.

Initial visual interpretation of the C–band images of part of the Barrie area indicate the recognition of fluted terrains and ancestral strandlines of glacial Lake Algonquin. Further interpretation will be conducted in the winter when preliminary geological maps are available.

At the Port Stanley site, a comparison was made between X–band (3 cm) and C–band (5 cm) SAR for material discrimination. The radar images were acquired in an area where the surficial materials were mapped in detail (Dreimanis and Barnett 1985). Materials present include the Port Stanley clayey silt till, ice–contact sand and gravel, glaciolacustrine sand, and silt and clay, and nearshore beach deposits of sand and gravel. Soil texture and moisture samples were taken during lake spring at the time of radar imaging.

Preliminary results to date indicate that the X–band imagery provides greater detail on surface micro–drainage than C–band. Surface micro–drainage patterns can be used as a measure for delineating surficial materials.

ACKNOWLEDGMENTS

This study is part of the Memorandum of Understanding signed between the Government of Canada (Canada Centre for Remote Sensing) and the Government of Ontario (Ontario Centre for Remote Sensing) for the evaluation of airborne C-band radar data for several resource mapping programs in Ontario.

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70. Project Number 83–41. Aggregate Resources Inventory in Peterborough County and Victoria County

C. Joan Dawson[1] **and Steve Szoke**[2]

[1]Geological Assistant, Aggregate Assessment Office, Engineering and Terrain Geology Section, Ontario Geological Survey, Toronto.

[2]Supervisor, Aggregate Assessment Office, Engineering and Terrain Geology Section, Ontario Geological Survey, Toronto.

INTRODUCTION

Field work discussed in this report was conducted in central southern Ontario during the 1988 field season as part of the Aggregate Resources Inventory Program. The purpose of this investigation was to delineate the aggregate deposits within the study area, and to determine the quantity and quality of the sand and gravel for use in both road–building and general construction applications. The results of this work will be published in Aggregate Resources Inventory Papers, or released in Open File Reports, as applicable. The areas involved in field investigations were:

1. Peterborough County
2. Victoria County (Figure 70.1)

Field investigations consisted of a number of activities including the examination of: potential aggregate deposits; existing pits and quarries; and of natural and man–made exposures. All active and abandoned pits were investigated, and at each site several observations were made including: face height, percentage gravel and sand, and the presence of deleterious materials such as chert, shale, clay, silt, and oversize boulders. At quarry sites, the height of the quarry face was noted, as well as bedrock geology and the presence of deleterious materials. Representative aggregate and rock samples were obtained at various sites and sent to the Ontario Ministry of Transportation (MTO) for analysis and testing.

Field observations were used to confirm and supplement the information gathered from various sources such as existing geological reports and maps, data from the files of MTO, and water well data from the Ontario Ministry of the Environment. The information resulting from this work is required for the evaluation of land development potential and for land use planning decisions.

Quaternary geology mapping by Finamore and Bajc (1983), Finamore and Courtney (1982), and Kaszycki (in preparation a, b) provided the framework for this detailed aggregate study. Reconnais-

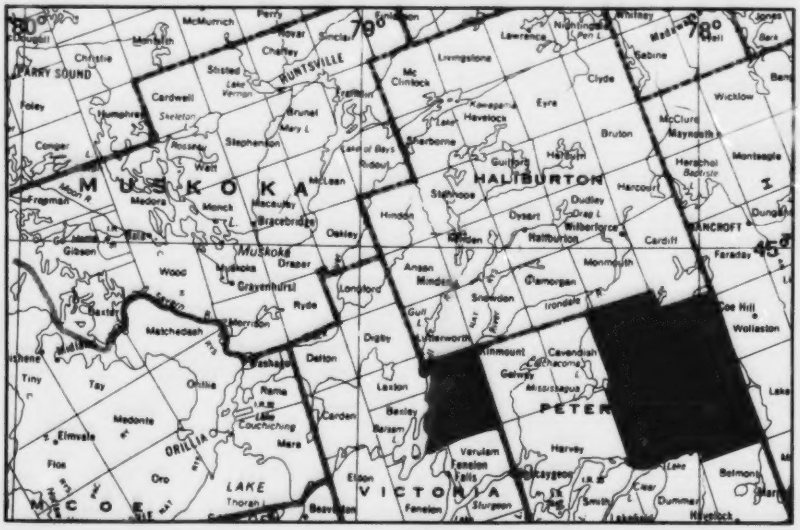

Figure 70.1. *Location map showing study areas in Peterborough County and Victoria County. Scale: 1:1 548 000 or 1 inch to 25 miles.*

sance level geological studies by Chapman (1975) and Chapman and Putnam (1984) also cover the area.

PETERBOROUGH COUNTY

The geographic townships of Burleigh, Anstruther, Chandos, and Methuen were investigated in Peterborough County. Gravel resources are scarce in all four townships, and only in Chandos Township are there extensive sand deposits.

The main sources of sand are the outwash deposits found near Jack Lake, and in the valleys of Eels Creek and the Crowe River. These valleys acted as conduits for meltwater flowing from the ice front towards the Kawartha Lakes. This system served as an outlet for glacial Lake Algonquin following deglaciation of the area (Chapman and Putnam 1984).

Ice–contact features provide a limited supply of gravel suitable for low specification road–building and general construction uses. These hummocky deposits are scattered throughout Anstruther and Chandos townships and the northern part of Burleigh Township. Till deposits have been used for cottage road construction in some of the areas where aggregate resources are scarce. However, till is generally unsuitable for use as aggregate because of the presence of excess fines and abundant oversize clasts.

The four townships are underlain by Precambrian rocks of the Central Metasedimentary Belt (Wynne–Edwards 1972) of the Grenville Province. This Belt consists mainly of gneisses, marbles, and granites (Bartlett *et al.* 1982; Bright 1981a, 1981b, 1988; Easton 1988; Shaw 1962). Marble has been quarried in two locations in the study area and it may be suitable for use as crushed stone. In northern Methuen Township, where naturally occurring sand and gravel deposits are almost nonexistent, highly weathered gneisses were being quarried primarily for use on cottage roads. Indusmin Limited operates a large system of quarries in central Methuen Township, extracting nepheline syenite for use in glass manufacturing.

Outliers of sedimentary rock of Paleozoic age are located in the southern part of Burleigh and Methuen townships (Carson 1980a, 1980b). Two quarries have been opened in the limestone beds of the Gull River Formation. The Gull River Formation is a valuable potential source of crushed stone because of the very limited supplies of crushable gravel in this area. Although aggregate may meet specifications, certain beds of the Gull River Formation may contain alkali–carbonate reactive rocks and for this reason may not be accepted by MTO for use in concrete aggregate. To alleviate this problem, MTO suggests either selective extraction to avoid reactive beds, or dilution of the aggregate with non–reactive rocks (Rogers 1985).

VICTORIA COUNTY

Somerville Township, Victoria County, was also investigated during the 1988 field season. Sand deposits are abundant in this township, however, gravel resources are limited. The most significant sand deposits were formed by meltwater which flowed from the ice front down the valley of the Burnt River toward the Kawartha Lakes (Chapman and Putnam 1984). Isolated remnants of glaciolacustrine sediments border thick deposits of clean outwash sand which flank the Burnt River. Although the fine–grained glaciolacustrine sediments are suitable only for use as fill, the coarser outwash materials can be used in low specification aggregate products. Gravel suitable for high specification aggregate uses is generally found only in ice–contact features. A knoll located north of the settlement of Rosedale appears to have the highest potential for supplying crushable gravel to the area. Several eskers located in the southern part of the township are largely depleted of material. In the southeastern part of the township, there has been sporadic extraction of till from the hummocky Dummer Moraines (Chapman and Putnam 1984), however, the till contains excess fines and abundant oversize clasts, and is usually suitable only for use as fill.

The northeastern half of Somerville Township is underlain by rocks of the Central Metasedimentary Belt (Wynne–Edwards 1972) of the Grenville Province. This area consists mainly of gneisses with small areas of marbles and granites (Easton and Bartlett 1984). No quarries have been developed in these Precambrian rocks.

Paleozoic age sedimentary rocks underlie the southwestern half of Somerville Township (Caley and Liberty 1952). The Shadow Lake Formation lies unconformably atop the Precambrian bedrock and consists of sandstone, siltstone, and shale. These rocks are generally not acceptable for use as aggregate. Overlying the Shadow Lake Formation are the limestones of the Gull River and Bobcaygeon formations. These limestones have been quarried for crushed stone for many years and are a valuable source of aggregate in this area. Although aggregate may meet specifications, certain beds of the Gull River Formation may contain alkali–carbonate reactive rocks and for this reason may not be accepted by MTO for use in concrete aggregate. Selective extraction to avoid reactive beds, or dilution of the aggregate with non–reactive rocks may resolve this problem (Rogers 1985).

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71. Project Number 86–19. Aggregate Resources Inventory of the Towns of Bracebridge and Gravenhurst, District Municipality of Muskoka

R.G. Gorman[1] and Steve Szoke[2]

[1]Resource Geologist, Aggregate Assessment Office, Engineering and Terrain Geology Section, Ontario Geological Survey, Toronto.

[2]Supervisor, Aggregate Assessment Office, Engineering and Terrain Geology Section, Ontario Geological Survey, Toronto.

INTRODUCTION

During the summer of 1988, aggregate assessments were undertaken in the towns of Bracebridge and Gravenhurst within the District Municipality of Muskoka. The geographic townships assessed include Macaulay, Muskoka, Draper, Oakley, Morrison, Ryde and parts of Monck, McLean, and Wood. These townships occupy an area of approximately 1110 km². Population centres in the report area include the towns of Bracebridge and Gravenhurst, as well as smaller communities such as Muskoka Falls, Vankoughnet, Coopers Falls, Severn Bridge, and Houseys Rapids (Figure 71.1).

The purpose of this investigation was to delineate the aggregate deposits within the study area, and to determine the quality and quantity of the sand and gravel for use in both road–building and general construction applications. This information is required for the evaluation of aggregate resources development potential and for land use planning decisions.

During the field investigation, all potential aggregate deposits were examined in detail using both natural and man–made exposures. Observations made at pit sites included the estimation of the face height, the percentage of gravel and sand, and the amount of objectionable materials present. Soil

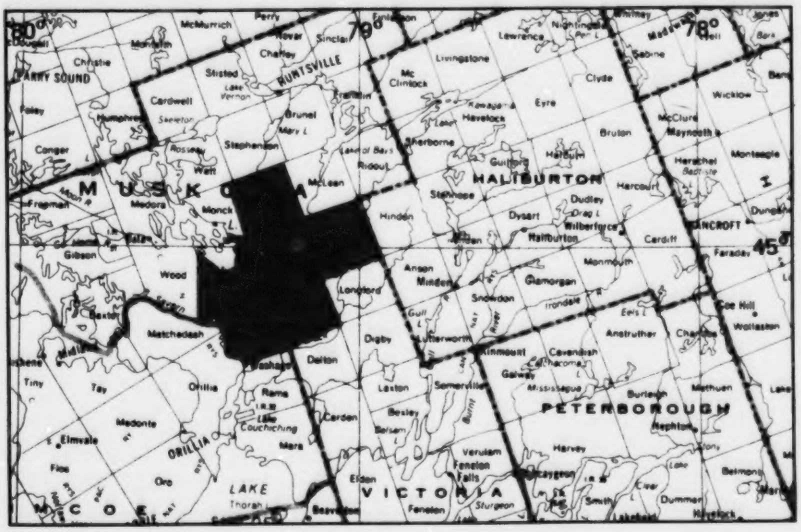
80°
79°
78°
45°
PARRY SOUND
HUNTSVILLE
MUSKOKA
HALIBURTON
BANCROFT
PETERBOROUGH
VICTORIA
ORILLIA
Christie
McMurrich
Perry
Chaffey
Sinclair
Stisted
Cardwell
Brunel
Stephenson
Watt
Medora
Monck
McLean
Wood
Gibson
Baxter
Matchedash
Dalton
Orillia
Rama
Lake Couchiching
Mara
Medonte
Oro
Tay
Tiny
Flos
Longford
Digby
Laxton
Bexley
Eldon
Carden
Fenelon
Verulam
Somerville
Anson
Minden
Hindon
Stanhope
Sherborne
Guilford
Dysart
Dudley
Harburn
Bruton
Harcourt
Cardiff
Monmouth
Glamorgan
Snowdon
Lutterworth
Kinmount
Galway
Cavendish
Harvey
Burleigh
Methuen
Anstruther
Chandos
Wollaston
Faraday
Dungannon
Monteagle
Herschel
Wicklow
McClure
Maynooth
Sabine
Lawrence
Nightingale
Livingstone
McClintock
Havelock
Eyre
Clyde
Smith
Dummer
Belmont
Conger
Foley
Humphrey
Freeman
Elmvale
LAKE

Figure 71.1. *Location map showing the towns of Bracebridge and Gravenhurst, District Municipality of Muskoka. Scale: 1:1 584 000 or 1 inch to 25 miles.*

This project A.2.3 is part of the five year Canada–Ontario 1985 Mineral Development Agreement (COMDA), a subsidiary agreement to the Economic and Regional Development Agreement (ERDA) signed by the governments of Canada and Ontario.

probing, hand augering, and geophysical techniques were used to assess subsurface materials in areas of limited exposure. A number of test holes were excavated using a backhoe, and aggregate samples were collected for quality testing.

Quaternary geological mapping by D.R. Sharpe (Geologist, Geological Survey of Canada, Ottawa, written communication, 1988) and Kaszycki (in preparation a, b) provided the framework for the detailed aggregate study. Reconnaissance level geological studies by Chapman (1975) and Chapman and Putnam (1984), and engineering terrain studies by Mollard (1980a, 1980b) also cover the area. Previous aggregate assessment work in the District Municipality of Muskoka has been undertaken by the Staff of the Algonquin Region of the Ministry of Natural Resources (1983).

BEDROCK

The bedrock in the project area is part of the Central Gneiss Belt of the Grenville Province. It consists largely of strongly foliated gneissic and migmatitic rock composed of quartz, feldspar, and biotite with garnet as a common accessory mineral (Meadows *et al.* 1987; Sharpe 1978). These rocks form prominent northwest–southeast–trending structural features which exerted strong control on glacial and glaciofluvial deposition (D.R. Sharpe, Geologist, Geological Survey of Canada, Ottawa, written communication, 1988). In general, the bedrock is hard and resistant to weathering, and may be considered a potential source of aggregate.

SURFICIAL GEOLOGY

A discontinuous cover of till was deposited within the project area by glacial ice which advanced in a south–southwesterly direction (Sharpe 1978). Exposures of this loose, stony, silty sand till are generally scarce. Where found, the till exists as a thin veneer over bedrock. Till is usually not well suited for aggregate use because it often contains excess fines and abundant oversize clasts. However, till may be a suitable source of fill in some localities.

Other glacial sediments in the area are generally located within bedrock–controlled valleys or basins. Such is the case with the glaciofluvial features which were deposited as the ice front melted back to the north. Two types of glaciofluvial deposits are represented in the project area:

1. ice–contact deposits which were laid down on or in close proximity to ice, including esker ridges; and
2. glaciofluvial outwash which was deposited by meltwaters flowing beyond the ice margin.

As the ice front melted northward, the area was inundated by glacial lakes. Where meltwaters flowed into these water bodies, glaciolacustrine deltas or subaqueous fans were formed. A considerable amount of glaciolacustrine sand, silt, and clay were deposited on the floor of these glacial lakes. These lakebed sediments occupy low–lying areas, notably near the centre of the Town of Bracebridge and along the branches of the Muskoka River (Sharpe 1978).

AGGREGATE DISTRIBUTION AND QUALITY

Glaciofluvial outwash deposits are the main sources of aggregate in the report area. Many of the major outwash deposits overlie bedrock–controlled plains and terraces above topographic lows adjacent to the north and south branches of the Muskoka River and adjacent valleys (D.R. Sharpe, Geologist, Geological Survey of Canada, Ottawa, written communication, 1988). The outwash largely consists of well stratified and uniformly bedded sand and gravel, and has been a traditional source of aggregate in the area. In some areas the outwash consists predominately of uniformly bedded sand, although concentrations of crushable gravel may occur locally.

The ice–contact deposits scattered throughout the project area are generally small; however, many of the deposits are important local sources of aggregate. Material exposed in these deposits varies from fine silty sand to coarse gravel suitable for crushing. The gravels frequently contain abundant oversize clasts which could be processed using a primary crusher. The occurrence of bedrock ridges in both outwash and ice–contact deposits is a common pit–workability problem that can hamper pit operations and estimation of remaining resources.

Scattered throughout the report area, especially north of the centre of the Town of Gravenhurst, significant aggregate resources are available from deltaic deposits. The deltas generally consist of stratified and uniformly bedded sand and gravel. Both pit run and crusher run construction products are produced from these features. Gravel is usually concentrated in pockets and/or in the upper levels of the pits. These deltaic deposits are generally well situated with respect to local markets.

An extensive subaqueous fan deposit located along King's Highway 11, in Morrison Township, is a major source of aggregate in the Town of Gravenhurst. Typically, the fan consists of fine to coarse sand, but also contains fine to coarse gravel. The aggregate in this feature tends to become finer near the surface, with fine to coarse gravel being concentrated in the lower levels of pits. In places the fan is capped by silt and clay. To avoid contamination of the underlying material, the silt and clay should be removed by stripping prior to aggregate extraction. In some areas, the fan contains gravel suitable for crushing if selective extraction and sand control measures are employed.

In general, the aggregate in the report area is hard and durable and suitable for a variety of road–building and general construction applications. The gravel generally contains low percentages of weathered and friable rock that could restrict its use in high specification products. Products available from pits in the area include asphaltic aggregate, as well as granular base course aggregate. Sandy aggregate has been found to be suitable for such uses as road sub–base, septic beds, and fill. Silt and clay seams, as well as silty fine sand units, are common in some pits and should be avoided during extraction for high specification aggregate uses. Although the aggregate from this area may meet Ministry of Transportation (MTO) aggregate testing specifications, based on field performance the local gravels are not accepted by MTO for use in portland cement concrete which will be exposed to de–icing salts. There is a bonding problem between the cement and gravel which results in spalling of the concrete. This spalling problem was observed on a bridge structure located north of the project area at Burks Falls (Armour Township, District of Parry Sound). Consequently, crushed limestone aggregate is imported from northern Simcoe County for high specification use.

In general, the report area contains large resources of sand. Resources of crushable gravel, however, are restricted, especially in Wood, Monck, and Draper townships. In many parts of the project area, much of the crushable gravel has been depleted and sand now dominates. In both the towns of Gravenhurst and Bracebridge, large tracts of land contain little or no aggregate resources. Consequently, aggregate may have to be transported lengthy distances to supply construction.

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72. Project Number 86–23. Aggregate Resources Inventory Northwest of Fort Frances, District of Rainy River

G.R. Jones[1] and Steve Szoke[2]

[1]Resource Geologist, Aggregate Assessment Office, Engineering and Terrain Geology Section, Ontario Geological Survey, Toronto

[2]Supervisor, Aggregate Assessment Office, Engineering and Terrain Geology Section, Ontario Geological Survey, Toronto.

INTRODUCTION

During the 1988 field season, work was undertaken in the area between Pipestone and Rainy lakes, northwest of Fort Frances in the District of Rainy River, as part of the Aggregate Resources Inventory Program (Figure 72.1). Portions of the study area appear on the Northwest Bay (52 C/13), Mainville Lake (52 C/14), Kakagi Lake (52 F/4), and Harris Lake (52 F/3) 1:50 000 scale map sheets of the National Topographic System. The purpose of this investigation was to locate sufficient resources of quality aggregate for future forest access road development. Specifically, this information is required by the Ministry of Natural Resources to help finalize route selection for a proposed forest access road.

Potential aggregate deposits in the project area were examined in detail during the field investigation. Soil probing, hand augering, and test pitting techniques were used to assess the nature of surface materials. Observations made at deposits included an estimation of deposit size and thickness, as well as the suitability of the sand and gravel for aggregate use. At various locations in the study area aggregate samples were collected for quality testing.

Quaternary geology mapping by Bajc and Gray (1987) provided the framework for the detailed aggregate study in the southwestern part of the project area. Reconnaissance level geological studies by Zoltai (1961, 1965) and engineering and terrain studies by Roed (1980a, 1980b) also cover the area.

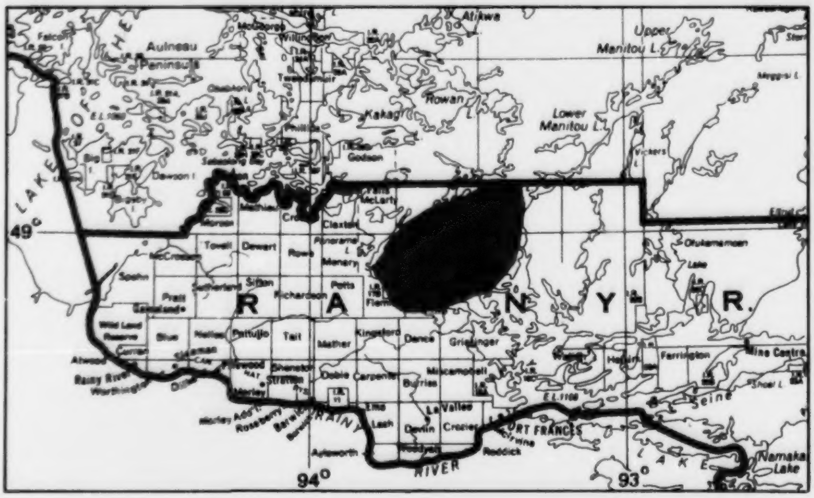

Figure 72.1. *Location map for project area northwest of Fort Frances, District of Rainy River. Scale: 1:1 584 000 or 1 inch to 25 miles.*

This project A.6.6 is part of the five year Canada–Ontario 1985 Mineral Development Agreement (COMDA), a subsidiary agreement to the Economic and Regional Development Agreement (ERDA) signed by the governments of Canada and Ontario.

BEDROCK

The project area lies within the southwestern part of the Superior Province of the Canadian Shield. Most of the area is underlain by granitic rocks (Blackburn 1981). The exception is a belt of predominantly metavolcanic rock which extends from Burditt Lake to Furlonge Lake along the western and northern boundaries of the study area. In general, the bedrock is hard and resistant to weathering, and is considered a potential source of aggregate.

SURFICIAL GEOLOGY

A discontinuous cover of till was deposited throughout the project area by glacial ice which advanced in a southwesterly direction (Zoltai 1961, 1965; Bajc 1987; Bajc and Gray 1987; Cowan 1987). This sandy till generally exists as a thin veneer over bedrock, although in several areas significant thicknesses can be observed. These thicker till accumulations often flank bedrock knobs. Till is usually not well suited for aggregate use as it often contains excess fines and abundant oversize clasts. However, it may be a suitable source of fill in some localities.

As the ice front melted back, sand and gravel were deposited within a limited number of ice–contact features, including moraines which form northwest- to southeast-trending ridges in the area. The moraines were laid down during temporary halts of the melting ice margin as the area was deglaciated. An esker ridge trends in a northeastern to southwestern direction near Calder Lake. The esker was deposited by meltwaters flowing in a tunnel complex under the ice or in a re–entrant at the ice front. Ice–contact material was also deposited in kame–like features along the southern flank of several bedrock knobs and ridges.

During deglaciation, much of the land surface was submerged beneath glacial lake waters. On the floors of these lakes, silty fine sand, silt, and clay were deposited. These lakebed sediments occupy low–lying tracts throughout the project area. A thin, discontinuous layer of silt and clay also caps a number of the ice–contact features.

AGGREGATE DISTRIBUTION AND QUALITY

Moraine ridges are important potential sources of aggregate in the area. A major moraine, known as the Rainy Lake–Lake of the Woods Moraine (Zoltai 1961), is situated along the southwestern boundary of the report area. Significant aggregate resources also occur within moraines located near Furlonge and Gussie lakes, and between Loonhaunt and Kaiarskons lakes. The aggregate available from the moraines is of varying quality. In some locations, clean sandy gravel suitable for a variety of aggregate uses is exposed, while in other areas, the aggregate consists of lower quality material containing abundant fines and/or oversize clasts.

The esker ridge, located near Calder Lake in the central part of the project area, rises between 5 and 18 m above the surrounding terrain. Sandy fine to medium gravel, well suited for road construction purposes, is the predominant material in the ridge. This esker should be capable of providing aggregates for a significant length of road.

Ice–contact features which flank the south sides of bedrock ridges are scattered throughout the area. Although these deposits are usually of limited areal extent, many of the deposits are well situated within the proposed road corridor. Material exposed in these features usually ranges from medium sand to coarse gravel. Some of the deposits may contain variable amounts of oversize clasts and/or fines.

Despite a general lack of known sand and gravel deposits in the area, sufficient resources were discovered to help alleviate potential aggregate shortages during future forest access road construction, and to reduce long haulage distances. The exception is an area located north of Ottertail and West Jackfish lakes in which aggregate resources are extremely limited.

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73. Project Number 88–19. The Delineation of Buried Aggregate Resources in the Pinehurst and Leamington Areas of Southwestern Ontario Using Electromagnetic Conductivity

Douglas G. Vanderveer[1] **and Steve Szoke**[2]

[1] Aggregate Resources Specialist, Aggregate Assessment Office, Engineering and Terrain Geology Section, Ontario Geological Survey, Toronto.

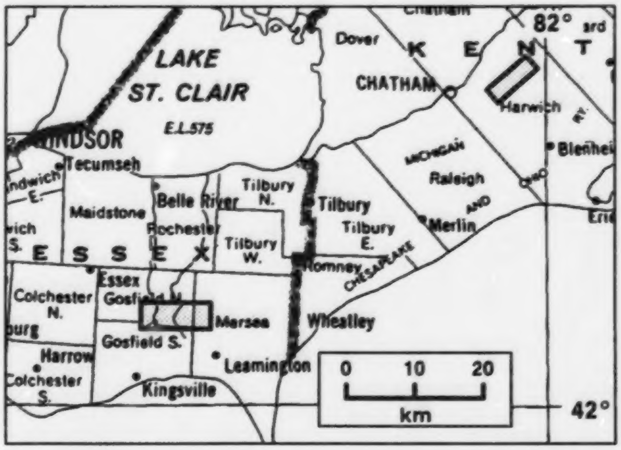
[2] Supervisor, Aggregate Assessment Office, Engineering and Terrain Geology Section, Ontario Geological Survey, Toronto.

INTRODUCTION

Surficial deposits of good quality sand and gravel are limited in Essex, Kent, and Lambton counties, southwestern Ontario. The material in most known deposits is generally of poor quality because of high shale and silt contents, and as such, is generally unsuitable for use in concrete or asphaltic aggregate applications. There are, however, two deposit areas which contain notable quantities of quality aggregate: (a) the subsurface "Pinehurst" deposit (informal name) located 11 km east of Chatham in Harwich Township, Kent County; and (b) the Leamington deposits, spread over a 21 km^2 area immediately west and northwest of the Town of Leamington, within North Gosfield, South Gosfield, and Mersea townships of Essex County (Figure 73.1). Pits in the Pinehurst and Leamington deposits are amongst the few known local sources of high quality aggregates located in this part of southwestern Ontario. Local supplies of quality aggregates are supplemented by materials imported by truck from surrounding regions to the west and northwest, or shipped into the area by lake freighter from more distant sources in Canada and the U.S.A. (James Lau, Petroleum Resources Geologist, Ministry of Natural Resources, personal communication, 1987).

PROJECT OBJECTIVES

The objective of this multiyear project during the 1988 field season was to determine the best methods to effectively delineate the boundaries of buried aggregate deposits, using the Pinehurst and Leamington deposits as test cases. Particular emphasis was placed on those areas of sand and gravel that are buried by other glacial, fine–grained glaciolacustrine or eolian sediments. The results of this methodological assessment will be incorporated into a broader–based program to complete the aggregate inventory in southwestern Ontario. In future years, the project will focus on locating and delineating additional aggregate reserves, most of which are expected to be buried in a setting similar to those at Pinehurst and Leamington. These materials are required to satisfy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Maidstone
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Tilbury N.
Tilbury
Tilbury E.
Rochester
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Romney
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Leamington
Colchester S.
Kingsville
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10
20
km
42°

Figure 73.1. *Location map for the Pinehurst and Leamington survey areas.*

an increasing demand for aggregates in southwestern Ontario.

SELECTION OF SURVEY METHODOLOGIES

Previous aggregate assessments (Ontario Geological Survey, in preparation) and Quaternary mapping programs (Kelly, this volume; Morris, this volume) in the area have not focused on defining the boundaries of buried aggregate deposits. To accomplish this task, a method with the capability of "seeing" through the overlying mantle of glacial till or glaciolacustrine sediments in order to delineate the sands or gravels beneath, was required. The use of drilling and/or backhoe testpits alone was not acceptable because of the amount of time and the high costs associated with the detailed grid pattern (100 to 200 m spacing between holes) survey necessary for adequate delineation. In addition, difficulty in obtaining permission to access private properties for a large-scale drilling or testpitting program was anticipated. An alternative method, such as a geophysical or remote sensing technique, was therefore required.

A review of remote sensing technology and three applicable geophysical techniques (seismic, resistivity, and conductivity) was undertaken prior to the 1988 field season. Remote sensing may have some application in identifying potential areas of buried deposits that are partly exposed at or near the surface. However, it was eliminated as a detailed delineation tool since burial beneath a few metres or more of overburden effectively prevents the detection of buried aggregates using current remote sensing technologies.

Based on previous work concerning buried aggregates in eastern Ontario (Gorrell, in preparation), it appeared that seismic reflection surveys could have some application in areas of deeper overburden. Such is the case at Leamington, where the depth to bedrock is in the range of 60 m. Seismic reflection was not effective in areas of shallower materials, such as at Pinehurst, where the depth to bedrock is approximately 20 m. Refraction primary compressional waves (P waves) do not normally provide a reflector from a lower velocity sand or gravel beneath a higher velocity clay or till layer, whereas shear wave (S wave) refraction soundings may allow identification of buried granular materials (Lloyd Thompson, Regional Geophysicist, Southern Ontario Region, Ministry of Northern Development and Mines, Tweed, personal communication, 1988).

Computer modeling, based on the stratigraphy of the Pinehurst deposit and the anticipated resistivities of the various units, indicated that resistivity soundings should be able to identify buried sand or gravel layers a minimum of 5 to 10 m thick. This would be the case provided there was a sufficient resistivity contrast between the sand and the overlying clay or till, and that the latter had a maximum thickness of 10 m. Similar modeling of conductivity soundings and a review of a similar study to locate aggregates conducted for the Ministry of Transportation (Bird and Hale Ltd. 1987), indicated that the Geonics EM31 and EM34-3 conductivity instruments might be useful in distinguishing areas underlain by sand and gravel. The limitations with regard to the effectiveness of these instruments in identifying aggregates below the water table, or within multilayer sequences of varying conductivities was unknown. To obtain information about the stratigraphy of buried deposits would require more intensive and time consuming EM techniques.

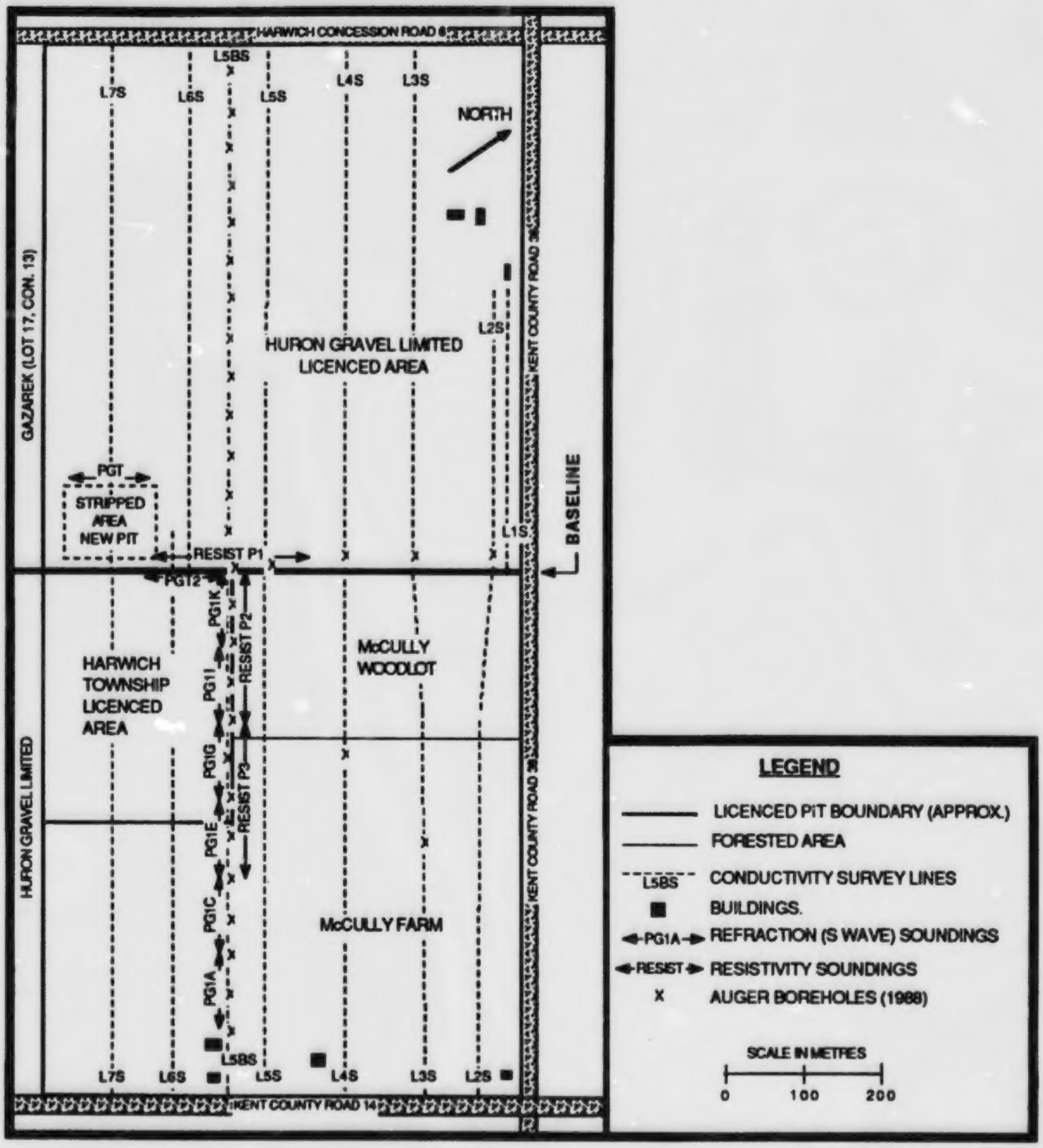
Based on the results of these studies, the 1988 field program was designed to evaluate various geophysical equipment and techniques. As a result of this evaluation, technique(s) were identified that are cost and time effective, for both local and regional surveys, while being capable of providing sufficient data for deposit delineation. Drilling and testpitting to verify the geophysical results and to obtain samples for quality testing was included in the program.

PINEHURST AREA

OVERBURDEN SEQUENCE

The buried sand and gravel deposit at Pinehurst was deposited in association with other glacial and glaciolacustrine sediments. The local stratigraphy is represented in a newly developed pit owned by Huron Gravel Limited of Chatham (for location *see* Figure 73.2). The exposure reveals a discontinuous mantle of fine eolian tan brown sands (up to 3 m thick) capping 1 to 2 m of mottled brown to grey-brown silt and clay, that in turn overlies 1 to 4 m of grey silt- and clay-rich, compact till. In the thickest parts of the aggregate deposit, greater than 15 m of sand and gravel occur beneath this till unit. Bedrock is not exposed, but Kettle Point Shale is expected to underlie the area.

The majority of the extractable sands and gravels in the area occur beneath the impervious silt/clay and till units, and are below the water table. Extraction of this material is accomplished using drag lines and bucket dredges. The material is stockpiled for subsequent processing and benefication using heavy media separation to remove deleterious shale particles. Currently, there are two operators in the area; Huron Gravel Limited and Adams Sand and Gravel Limited. The latter is expected to cease extraction in the near future because of a lack of reserves (Don Mason, General Manager, Adams Sand and Gravel Limited, Harwich Township, personal communication, 1988). A licence has recently been issued to the Township of Harwich to operate a pit on a site adjacent to Huron Gravel Limited.


HARWICH CONCESSION ROAD 6
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L7S
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L5S
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L3S
L2S
L1S
NORTH
HURON GRAVEL LIMITED LICENCED AREA
GAZAREK (LOT 17, CON. 13)
KENT COUNTY ROAD 38
BASELINE
PGT
STRIPPED AREA NEW PIT
RESIST P1
PG12
PG1K
PG1I
PG1G
PG1E
PG1C
PG1A
RESIST P2
RESIST P3
McCULLY WOODLOT
HARWICH TOWNSHIP LICENCED AREA
HURON GRAVEL LIMITED
McCULLY FARM
KENT COUNTY ROAD 14
LEGEND
LICENCED PIT BOUNDARY (APPROX.)
FORESTED AREA
CONDUCTIVITY SURVEY LINES
BUILDINGS.
REFRACTION (S WAVE) SOUNDINGS
RESISTIVITY SOUNDINGS
AUGER BOREHOLES (1988)
SCALE IN METRES
0
100
200

Figure 73.2. *Pinehurst buried aggregate delineation survey area – location of EM31, EM34-3 conductivity surveys, seismic and resistivity soundings (all property and licenced pit boundaries are approximate).*

SELECTION OF TEST AREA

Data previously recorded from 17 drillholes and 37 backhoe testpits was made available to the authors by Huron Gravel Limited and the Township of Harwich. This data facilitated the selection of a test site that encompassed both a known area of gravel deposition (e.g. licenced pit properties) and parts of the adjacent farmlands which were expected to be devoid of aggregate. The test area is bound on the southeast by Kent County Road 14, on the northeast by Kent County Road 38, and on the northwest by Harwich Township Concession Road 6. Both private property and licenced pit property are adjacent to the area in the southwest. A transect across the Pinehurst deposit, consisting of a strip 700 m wide and 1360 m long, was selected for these trial surveys (Figure 73.2).

TABLE 73.1. EXPLORATION DEPTHS FOR EM31 AND EM34-3 AT VARIOUS INTERCOIL SEPARATIONS (AFTER MCNEIL 1980).

Unit	Intercoil Spacing (metres)	Horizontal Dipole (metres)	Vertical Dipole (metres)
EM31	N/A	3.0	6.0
EM34-3	10	7.5	15
EM34-3	20	15	30
EM34-3	40	30	60

A northeast–southwest trending baseline parallel to, and midway between, Kent County Road 14 and Harwich Township Concession Road 6 was positioned over the main part of the unmined portion of the Pinehurst deposit. Grid lines perpendicular to the baseline were selected at roughly 100 m intervals along the baseline. The location of each line was subsequently chained in along the baseline.

FIELD TRIALS

A Geonics EM31 Conductivity Meter, a Geonics EM34–3 Conductivity Unit, and a Soiltest Strata Scout Resistivity Meter were evaluated in the first week of field work. The use of refraction P waves and S waves were evaluated by Lloyd Thompson, Regional Geophysicist, Southern Ontario Region, Ministry of Northern Development and Mines. John Greenhouse, Head, Department of Earth Sciences, University of Waterloo, visited the area and conducted additional resistivity soundings. The location of each of these soundings within the test area is shown on Figure 73.2.

The EM31 and the EM34–3 can provide profiles across materials of varying conductivities with a variable frequency of soundings (e.g. every 10, 20, or 40 m along survey lines). This cannot be readily achieved using refraction seismic or resistivity soundings. The EM31 measures the conductivity of the upper 3 m of the surface when operated in a horizontal dipole mode, and up to 6 m when in the vertical dipole mode. The EM31 provided conductivity soundings indicative of: (a) thin surface ridges of fine-grained sands (lower conductivity); (b) near surface layers of clay or till (higher conductivity); and (c) areas where aggregates occur very near the surface (lower conductivity). The EM34–3 has a greater depth of sounding penetration and can distinguish sand and gravel buried deeper beneath clay and till (Table 73.1). A survey using both the EM31 and the EM34–3 collected a variety of conductivity data associated with different penetration depths of sounding. Various coil configurations (horizontal and vertical dipoles) for each unit, and varying intercoil spacings (10, 20, and 40 m) for the EM34–3, were employed to determine the optimum technique. For a more detailed description of these instruments and techniques the reader is referred to McNeil (1980).

Resistivity work with the Soiltest Strata Scout unit was unsuccessful in obtaining a sounding. This may, in part, have been because of a lack of moisture in the surface units, or because of the low amperage output of the unit. Greenhouse's work using a resistivity unit with a much higher amperage output was able to provide adequate soundings within the area (*see* Resistivity Soundings, Figure 73.2). Interpretation of these soundings using the computer program "RESIST" revealed a five–layer model for all soundings (John Greenhouse, personal communication, 1988). This result is comparable to the sediments exposed in section in the nearby pit (described previously) and identified in drilling records.

Thompson conducted various refraction surveys including P wave and S wave refraction soundings at selected sites. The majority of these were carried out along Line 5B South (*see* Refraction Soundings, Figure 73.2). Preliminary interpretation of this data indicates that the S wave refraction soundings were successful in identifying the upper boundary (reflector) of aggregates buried 4 to 10 m beneath clay or till (Lloyd Thompson, personal communication, 1988). The contact between the clays and till was not distinguished using S wave refraction, whereas P wave refraction soundings provided a reflector of this interface, but not of the till–aggregate boundary. A bedrock surface reflector, 20 to 22 m below the surface, was identified during S wave soundings. The S wave refraction technique, therefore, appears suited to the identification and determination of the thickness of sand and gravel beneath till or clay overburden, provided there is a sufficient velocity contrast between the aggregate materials and the overburden.

RESULTS OF CONDUCTIVITY SURVEY

Test trials at Pinehurst were successful in providing a range of readings for the soundings using both the EM31 and the EM34–3, and enabled the construction of conductivity profiles for the deposit. The EM31 gave more consistent readings when operated in the vertical dipole orientation and, although sometimes erratic between stations, the soundings could be used along some lines to define the location of major sand and gravel deposition. This was particularly true where the aggregate was exposed at or very near the surface (Figure 73.3a). The EM31 readings obtained using the vertical dipole were generally 3 to 10 mmhos/metre higher than readings obtained using the horizontal dipole, and showed greater contrast between areas where aggregate was near the surface (e.g. 0 to 400 m south of Baseline, Figure 73.3a) and areas known to be devoid of aggregates (e.g. 500 to 800 m south of Baseline, Figure 73.3a).

The EM34–3 operated with a 20 m coil spacing using the horizontal dipole position (coils held in a

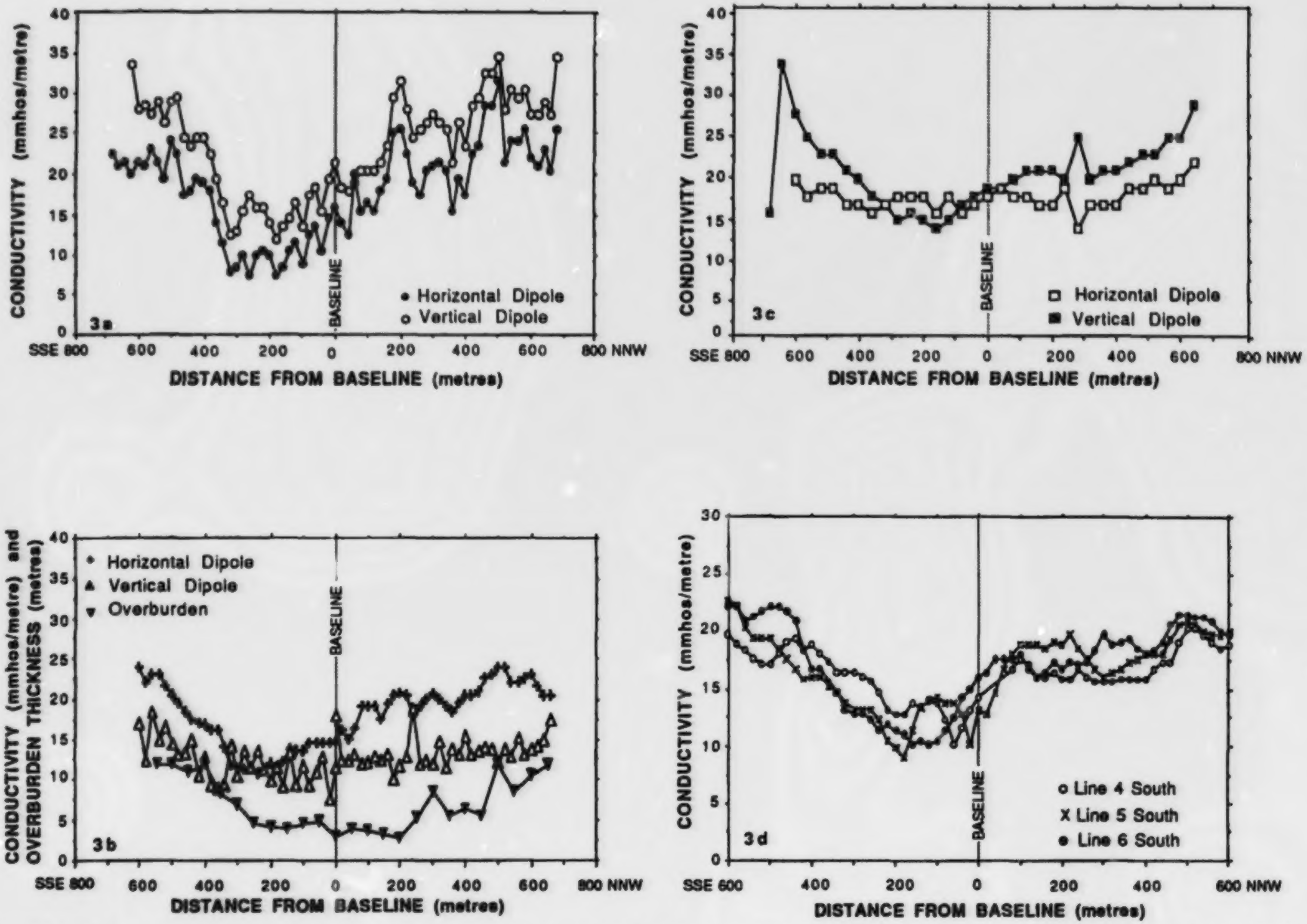


Figure 73.3. *Conductivity profiles and overburden thickness, Pinehurst area - (a) EM31, Line 5B South; (b) EM34-3, 20 m coil separation, also showing thickness of overburden as determined from borehole records, Line 5B South; (c) EM34-3, 40 m coil separation, Line 5B South; (d) EM34-3, horizontal dipole, 20 m coil separation, Lines 4, 5, and 6 South.*

vertical plane) provided the smoothest profiles and the best resolution of the location of the buried aggregate deposits (Figure 73.3b). Readings for the EM34-3 operated in vertical dipole (coils laid horizontally on the ground) were generally lower and more erratic than the horizontal dipole readings for the same intercoil spacing. Similarly, when the EM34-3 was operated with a 40 m intercoil separation, readings were generally higher and provided less contrast between areas underlain by aggregates versus those expected to be devoid of aggregate (Figure 73.3c). In the initial testing, the EM34-3 with a horizontal dipole and an intercoil spacing of 20 m appeared more successful in providing conductivity profiles indicative of aggregate deposition, as demonstrated by the conductivity profiles for Lines 4, 5, and 6 South shown on Figure 73.3d. Permission was obtained to undertake work on adjacent farms and the baseline was extended approximately 1.5 km to the north-northeast and 2.5 km to the south-southwest. Conductivity surveys in the expanded area were conducted using horizontal and vertical dipoles with the EM31 and the EM34-3 (the latter with a 20 m intercoil spacing) along grid lines spaced about 100 m apart. The data from these surveys has been entered into a computer data file and additional analyses will form the basis of the delineation of this deposit.

CORRELATION OF CONDUCTIVITY AND DRILLING

Drilling greatly facilitated the interpretation of the geophysical data and assisted in the subsequent planning of the conductivity survey used to delineate the area of buried aggregate. A truck-mounted auger and a drilling crew were provided by the Ministry of Transportation. The drill unit consisted of a 6.5 m hydraulic kelly-bar to which 5.5 m of 20 cm wide flight augers could be attached, allowing penetration and limited sample recovery to a maximum depth of 12 m. If the water table was encountered during drilling, sample recovery was very poor and drilling was often abandoned. A total of 30 boreholes were drilled over a five-day period.

Drilling was conducted at 50 m intervals along Line 5B South (Figure 73.2), the same line used for the seismic and resistivity soundings. This line of boreholes provided a transect of the deposit and allowed an evaluation of EM surveys. It also allowed an opportunity to test for a correlation between the conductivity soundings and the depth of overburden over the aggregates. The drilling was used to evaluate the seismic and resistivity interpretations. A number of additional holes were drilled along part of the baseline, and two holes were drilled on adjacent lines in areas where mid-range conductivities indicated a potential for buried aggregates.

The drilling showed a fairly strong correlation between the EM34-3 conductivity measurements (20 m coil separation, horizontal dipole) and the depth of overburden materials (Figure 73.3b), particularly southeast of the baseline. Conductivities of less than 15 mmhos/metre appear to indicate the presence of aggregates under less than 5 to 9 m of clay or till. Conductivities of greater than 20 mmhos/metre indicate depths of overburden greater than the depth of drilling (12 m). Additional drilling is planned in areas were conductivity soundings suggest the presence of buried aggregates, and will be used to verify the limits of buried sand and gravel.

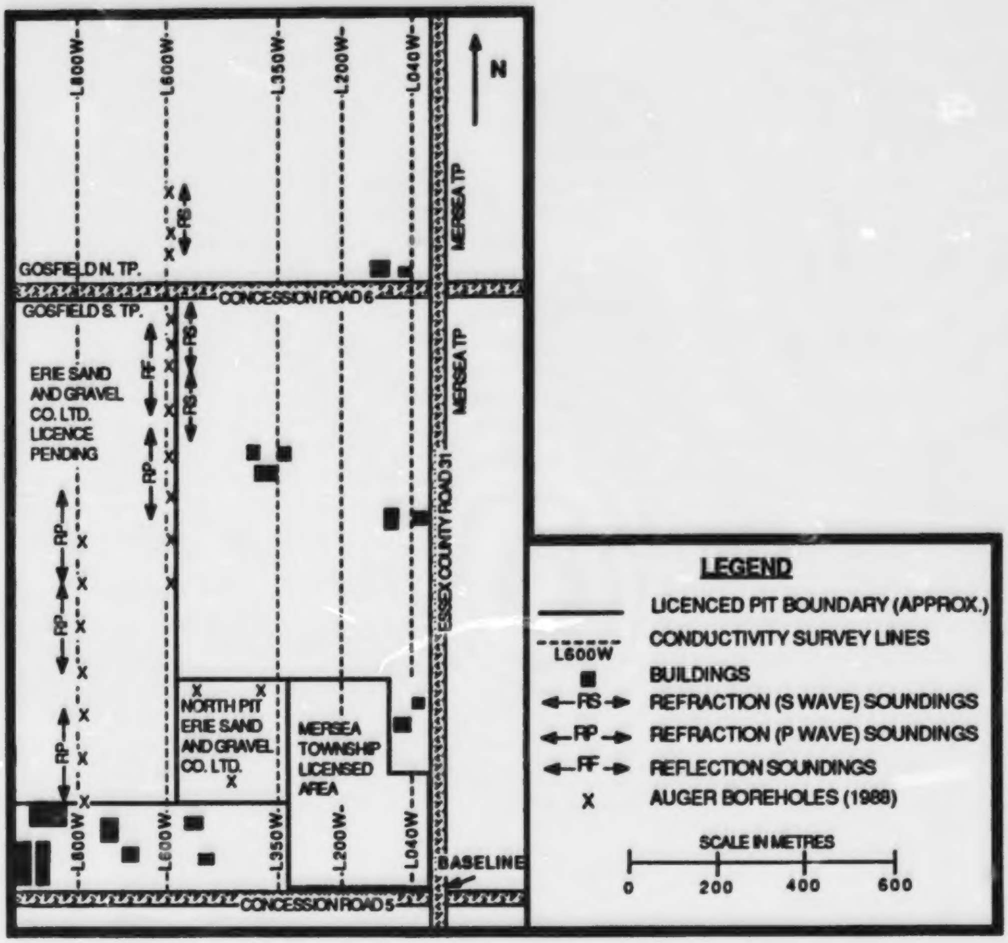
LEAMINGTON AREA

OVERBURDEN SEQUENCE

Extraction in the Leamington area has occurred on top of, and along the flanks of, the only prominent topographic feature in the area – the Leamington Moraine (Chapman and Putnam 1984). The moraine has a maximum elevation in excess of 225 m. Most extraction has occurred above 205 m. Some material has been extracted from below the water table. This extraction was probably terminated when the underlying silt- or clay-rich materials were encountered. The number of active commercial producers in the area has decreased in recent years. Other licenced pits are operated by the County of Essex and the local townships.

The stratigraphy of the Leamington deposits is partly exposed in the "north pit" operated by Erie Sand and Gravel Company Limited of Leamington (Figure 73.4). The west wall of the pit consists of 0 to 8 m of medium to fine-grained tan brown sands overlying 0 to 2 m of tan brown pebble gravel atop 10 m or more of medium to coarse grey to grey-brown sand with some gravel. The lower, coarser sand unit is of interest because it is of higher quality and is suitable for use in concrete and asphaltic applications. The upper sands are used mainly for fill. A different depositional sequence is revealed on the east wall of the pit where 2 to 5 m thick tongue of grey silt-clay rich till is exposed under 1 to 2 m of sand and gravel. Extraction of this till for use in a local landfill site has revealed an underlying tan to rust brown, medium to coarse sand unit of unknown thickness in the northeastern corner of the pit. The southeastern corner of the pit reveals a capping of sand (similar to that exposed at the top of the section along the west wall of the pit) which overlies glaciolacustrine silt and clay over till, that in turn sits on medium to coarse grey sand. The regional stratigraphic significance of these units are more fully described by Morris (this volume). Bedrock is not exposed in the area and water well records indicate at least 60 m of overburden.

Water tables in the area are quite variable and occur at two or more levels. Some perched water tables are present where glaciolacustrine silt and clay or silt-clay rich till units prevent drainage into underlying sand and gravel units. The sand and gravel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L200W
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CONCESSION ROAD 6
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NORTH PIT ERIE SAND AND GRAVEL CO. LTD.
MERSEA TOWNSHIP LICENSED AREA
ESSEX COUNTY ROAD 31
BASELINE
CONCESSION ROAD 5
LEGEND
LICENCED PIT BOUNDARY (APPROX.)
CONDUCTIVITY SURVEY LINES
BUILDINGS
REFRACTION (S WAVE) SOUNDINGS
REFRACTION (P WAVE) SOUNDINGS
REFLECTION SOUNDINGS
AUGER BOREHOLES (1988)
SCALE IN METRES
0
200
400
600

Figure 73.4. *Leamington buried aggregate delineation survey area – location of conductivity survey lines and seismic soundings (all property and licenced pit boundaries are approximate).*

are extracted by front end loaders, or by larger backhoes in areas of perched water tables.

SELECTION OF TEST AREA

Although there are substantial amounts of sand exposed in various pits in the area, most is of poor quality for concrete or asphaltic applications. There is a limited supply of higher quality materials such as that found in the lower levels of the northern pit (described above) operated by Erie Sand and Gravel Company Limited.

Efforts to assess techniques that could be used to delineate high quality sand buried either beneath poorer quality sand, or clay or till were concentrated along the northern edge of the depositional area. Test pit data on property recently optioned to Erie Sand and Gravel Company Limited was made available and provided a preliminary means of validating the conductivity readings obtained during the initial EM surveys along lines L600W and L800W in this area (Figure 73.4).

An east–west trending baseline along South Gosfield Township Concession Road 5, perpendicular to Essex County Road 31 in South Gosfield and Mersea townships, was selected (Figure 73.4). Grid lines off the baseline, parallel to Essex County to Road 31 and spaced 150 to 200 m apart, were established between Concession Road 5 and Concession Road 6. These were extended into areas expected to be devoid of aggregates in order to establish the background range of conductivities in areas of clay or till. Two lines (L600W and L800W) were selected for the trial surveys. Based on experience gathered at Pinehurst, the survey concentrated on collecting conductivity readings using the EM34–3 in the horizontal dipole mode using both a 20 m and a 40 m intercoil separation.

FIELD TRIALS

In areas expected to be underlain by 10 to 18 m of sand, the EM34–3 soundings using the 20 m coil separation had very low conductivities (5 to 10 mmhos/metre) (Figure 73.5). Between 1000 and

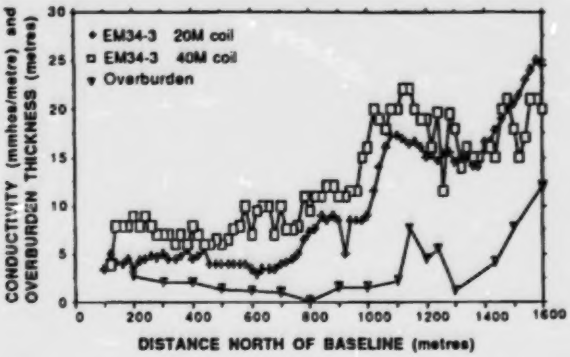

Figure 73.5. *EM34–3 conductivity profiles (horizontal dipoles, Line 600 West) and overburden thickness from boreholes (combined Line 600/800 West), Leamington area.*

1100 m north, the conductivity increased, then decreased across a band of glacial till exposed at the surface. The conductivity then increased north of 1400 m indicating deepening overburden and/or the absence of aggregates below the surface. These preliminary results indicate that the EM34–3, operated in a horizontal dipole mode with a 20 m coil spacing, adequately defines the presence of thick near-surface sands or gravels with very low conductivities.

The conductivity soundings (10 to 18 mmhos/metre), using a 20 m intercoil separation, indicated that the area in the vicinity of Concession Road 6 may be underlain by a sand unit not previously identified. This hypothesis was substantiated by later seismic work and confirmed by subsequent drilling.

Soundings using the EM34–3 (horizontal dipole) and a 40 m coil spacing generally showed slightly higher readings and variations not recorded using a 20 m coil spacing. This is perhaps a reflection of variations in conductivities of either more deeply buried unconsolidated units or within the bedrock.

Seismic surveys along test lines L600W and L800W (Figure 73.4), were conducted by Thompson. These surveys included: refraction P wave soundings in areas of deep sand and gravel expected to be devoid of significant layers or seams of clay or till; and, reflection and refraction S wave soundings in areas suspected to be underlain by till or clay. Refraction P wave soundings identified the following contacts: (a) the topsoil mantle over fine-grained sands; and, (b) the water table. This technique could not distinguish the contact between the poorer quality sands and the underlying coarser sand and gravel units (Lloyd Thompson, personal communications, 1988). Reflection soundings (P wave) in areas of complex stratigraphy provided the most information. Reflectors are thought to indicate the topsoil/till, till/sand–gravel, and sand–gravel/bedrock contacts. Shear wave refraction in areas of till over sand and gravel discerned the contact between the till and underlying aggregates, but gave no further reflectors because the thickness of sediments absorbed or diminished the seismic signal.

CORRELATION OF CONDUCTIVITY AND DRILLING

Boreholes were drilled using the Ministry of Transportation drill along lines L600W and L800W (Figure 73.4). There is a strong correlation between the conductivity results and the thickness of sand and the amount of overlying material (Figure 73.5). In areas with lower conductivities (less than 10 mmhos/metre), little silt or clay cover was encountered and drilling (to a maximum depth of 12 m) terminated in sand. Boreholes in areas with conductivities of 10 to 18 mmhos/metre, encountered 4 to 9 m of clay or till over sand. Drilling in areas of higher conductivities (greater than 20 mmhos/metre) revealed only overburden.

FACTORS AFFECTING CONDUCTIVITY SURVEY

Drawbacks to the use of conductivity surveys include: (a) difficulty in obtaining stable readings during periods of atmospheric electrical interference; and (b) abnormally high or low readings for all configurations of the EM31 and EM34–3 when readings are taken within 50 to 100 m of power and buried gas lines, or near water lines, drainage tiles, metal fences, or open water. This is particularly evident if the intercoil orientation is parallel to the trend of these linear features. In these situations, the instrument is often electronically overloaded and no accurate reading is possible. These limitations must be addressed during planning for a conductivity survey, and when interpreting the data collected. In general, the EM31 operated in a vertical dipole mode and the EM34–3 operated in the horizontal dipole position with a 20 m coil spacing are not as susceptible to these types of interference.

CONCLUSIONS

The EM conductivity surveys are time efficient and cost effective methods of delineating buried aggregates. These techniques are most effective when combined with drilling and supplemented by select geophysical and resistivity soundings.

The results of drilling in the middle range of conductivities (10 to 18 mmhos/metre) in the Pinehurst and Leamington areas verify the value of using the Geonics EM34–3 as a means of locating and delineating aggregates buried beneath upwards of 9 to 12 m of conductive overburden. The survey in the Leamington area indicates that conductivities of less than 10 mmhos/metre indicate sand or gravel exceeding 12 m in thickness with little or no silt– or clay–bearing cover.

Shear wave refraction soundings are useful in establishing the depth to the top of buried sand or gravel units. In areas of shallower bedrock (less than 25 m), they provide the depth to the bedrock surface, enabling the thickness of the sand or gravel to be determined. Resistivity soundings and reverse modeling are useful indicators of stratigraphy and unit thicknesses. Both resistivity and seismic soundings, although adding valuable data concerning the stratigraphy of a site, are extremely time consuming in comparison to an EM conductivity survey. The EM34–3 operated in the horizontal dipole with a coil spacing of 20 m is the preferred method to delineate buried aggregates in southwestern Ontario, and should be useful in surveys to locate additional buried reserves in this region.

ACKNOWLEDGMENTS

The program benefited from the cooperation of numerous private individuals and pit operators who provided test pit and drilling data as well as access to private properties. The authors benefited from discussions about glacial stratigraphy with Bern Feenstra, Regional Geologist, Southern Ontario Region, London, Ministry of Northern Development and Mines. Thanks are also extended to Lloyd Thompson and John Greenhouse for their respective contributions and discussions of the geophysical techniques used in this study. The use of the Ontario Ministry of Transportation's drilling rig and drilling crew is gratefully acknowledged. Derek Finley, Rob Bucci (on loan from the Ministry of Northern Development and Mines, London Regional Geologist's Office), and Joel Mejilla were cheerful and capable assistants and are thanked for their significant contribution to the project.

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74. Project Number 88–37. Paleozoic Geology of the Gypsum Deposits in the James Bay Lowland

R.K. Bezys[1] **and M.P. Bradshaw**[2]

[1]Geologist, Paleozoic/Mesozoic Geology Subsection, Engineering and Terrain Geology Section, Ontario Geological Survey, Toronto.

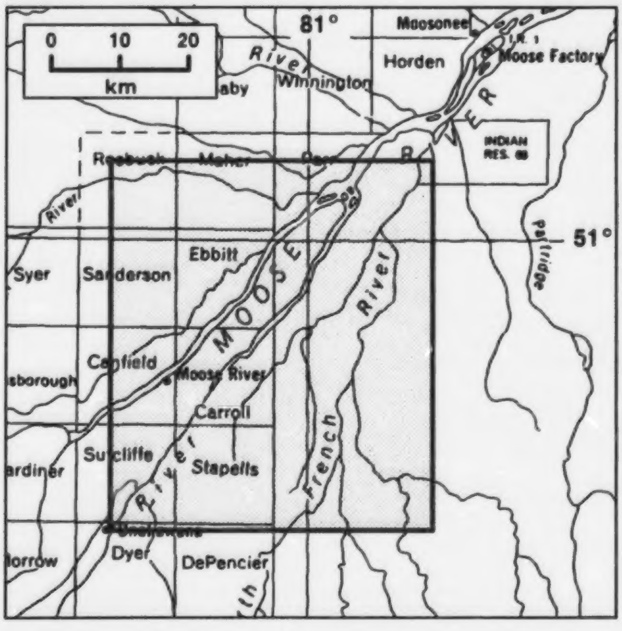
[2]Staff Geologist, Ministry of Northern Development and Mines, Timmins.

INTRODUCTION

Detailed Paleozoic mapping of the Middle Devonian Moose River Formation was undertaken in the James Bay Lowland in 1988, to delineate the distribution of its gypsiferous horizons.

A previous study of the gypsum deposits was undertaken by Guillet (1964), who conducted a general mapping expedition in the area. Since that time, there has been considerable interest in the geology and subsurface areal extent of these deposits. In the fall of 1987, reconnaissance work on the gypsum deposits was carried out by the Mineral Development Section of the Ontario Ministry of Northern Development and Mines, Toronto. As a result of encouraging data from this reconnaissance study, the present project was undertaken. The objective of the James Bay Lowland gypsum study is to present detailed geological information on, and a resource map of, these gypsum deposits.

The Moose River Formation outcrops along the Kwataboahegan, Cheepash, Moose, North French, Wakwayokastic, and Kiasko rivers, and at Gypsum Mountain in the James Bay Lowland. The main gypsum deposits are exposed along the banks of the Cheepash and Moose rivers, and at Gypsum Mountain (local name).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sborough
Carroll
Sutcliffe
Stapells
River
ardiner
French
Morrow
Dyer
DePencier

Figure 74.1. *Location of study area.*

CANADA ONTARIO

This project D.1.6. is part of the five year Canada–Ontario 1985 Mineral Development Agreement (COMDA), a subsidiary agreement to the Economic and Regional Development Agreement (ERDA) signed by the governments of Canada and Ontario.

LOCATION

The study area is 60 km southwest of Moosonee and approximately 270 km due north of Timmins (*see* Figure 74.1). The area lies within the Moose River Basin. The study area is delineated by Latitudes 50° 37′ and 51°05′N, and Longitudes 80°45′ and 81° 25′W. The areas mapped include: approximately 18 km of river bank exposures on the Cheepash River (both sides) in Roebuck and Maher townships; about 9 km of exposure on the Moose River in Canfield, Carroll, and Ebbitt townships; and approximately 1 km² of exposure at Gypsum Mountain (Stapells Township and the Kiasko River Area).

ACCESS

The study area is low lying and poorly drained, with significant bog development despite the presence of numerous rivers. The area can be accessed in the summer by train (the Ontario Northland Railway travels from Cochrane to Moosonee), river (canoe or inflatable boat), or helicopter. In the winter, access may also be gained by winter roads. For this field season, field equipment was transported by train to the community of Moose River (*see* Figure 74.1). From Moose River, a helicopter was used to transport the field equipment to the first base camp on an island in the middle of the Moose River (2.5 km northeast of Moose River). Halfway through the season, a camp move was made by helicopter to a second base camp on the Cheepash River, approximately 30 km north of Moose River.

The Moose River Formation outcrops along the Moose River were accessed with an inflatable boat (Zodiac®) fitted with a 9.9 HP motor. The low water level (and numerous rapids) on the Cheepash River required the use of a 17-foot aluminum canoe. The outcrops at Gypsum Mountain were accessed with the Zodiac®, after being flown into the area by helicopter.

GENERAL GEOLOGY

The Moose River Formation was first defined by Dyer (1929, 1930), but Martison (1953) redefined the stratigraphy and considered the Moose River Formation to be represented by the middle member of the Abitibi Formation. Sanford *et al.* (1968), and Sanford and Norris (1975), reinstated the term "Moose River Formation" to apply to Dyer's original definition of the unit.

The Moose River Formation appears in outcrop as an unfossiliferous sequence of limestone, argillaceous limestone, minor pelletoidal limestone, dolomitic limestone, brecciated carbonates, and gypsum. Shale, secondary selenite, and anhydrite may also be present (Sanford and Norris 1975). The Moose River Formation has a sharp contact with the overlying Murray Island Formation, a banded sequence of fossiliferous calcareous dolostone, limestone, and argillaceous limestone. The Moose River Formation is underlain by the Kwataboahegan Formation, which is a fossiliferous biostromal and biohermal limestone (Figure 74.2). Nowhere in the Moose River Basin is a complete section of the Moose River Formation exposed. The thickest known outcrop sequence is 17 m, on the Abitibi River at Long Rapids. The thickest drillhole sequence is the Mike Island drillhole at Moose River, at 89 m (Sanford and Norris 1975). Exposures of Moose River Formation limestone are rare on both the Moose and Cheepash rivers, and where present consist of a dark brown to tan, very finely to finely crystalline, laminated to massive limestone.

The maximum development of gypsum occurs along the Moose River Arch, a broad anticlinal northwest-trending basement high. This belt of gypsum is approximately 70 km long and about 17 km wide. In holes drilled to the southwest and northeast of this belt, only minor amounts of gypsum were intersected.

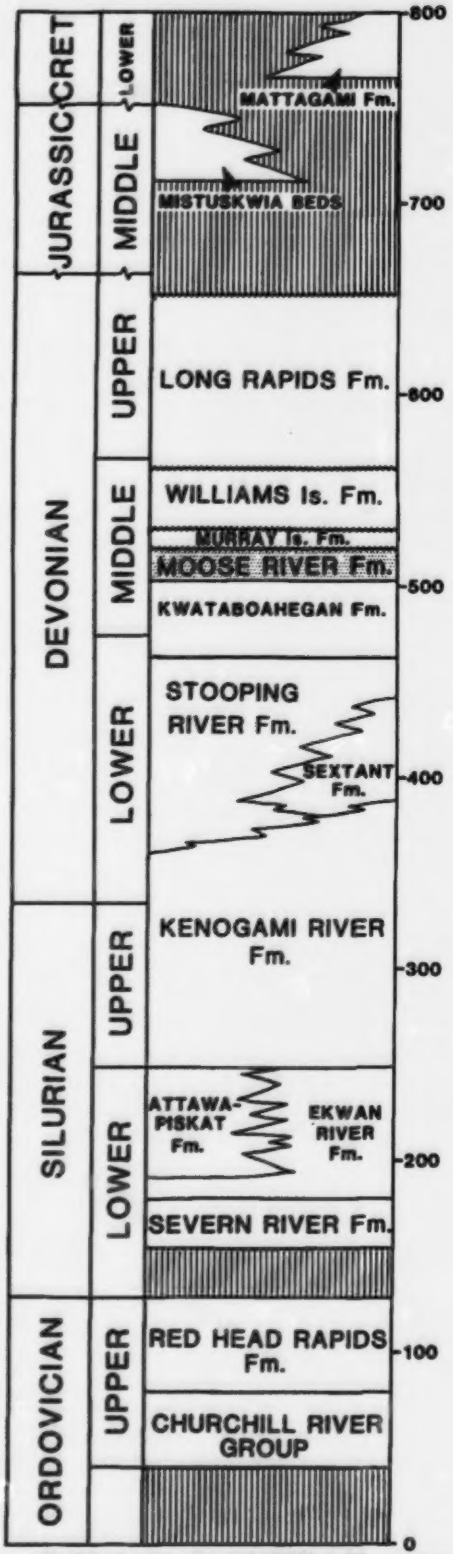
Gypsum was first reported in the Moose River Basin by R. Bell (1877). Subsequent reports by J.M. Bell (1904) and Dyer (1929) described in greater detail the gypsum sections, and the possible economic development of the deposits. The most recent publication describing the gypsum deposits was by Guillet (1964), who carried out a geological and economic investigation of the gypsum, augmented with drilling results from a program conducted by the Moosonee Gypsum and Exploration Company in 1963.

MOOSE RIVER GYPSUM EXPOSURES

Exposures of gypsum occur on the Moose River, north of the Ontario Northland Railway bridge at the community of Moose River. The north bank outcrops extend for approximately 4 km, and the south bank exposures extend for approximately 3.5 km. A second outcrop of gypsum, approximately 1 km in length, occurs 11 km east of the railway bridge on the south bank of the Moose River.

The Moose River gypsum exposures consist predominantly of two units: 1) massive to banded pure gypsum; overlain by, 2) gypsum breccia. Outcrop exposures of both units range in thickness from less than 0.5 m to 5 m, with an average thickness of 2.5 m. The lower gypsiferous unit typically consists of medium to finely crystalline massive white gypsum, with a chickenwire mosiac texture. The colour of the gypsum varies through white, orange, pink, brown, and grey. The massive gypsum in some exposures grades into an interbanded unit of dark brown selenite and white gypsum. Some outcrops of massive white gypsum have abundant, medium to finely crystalline, dark brown selenite eyes, which give them a distinctive appearance.

The massive white gypsum unit has a sharp contact with the overlying gypsum breccia unit. The breccia is a conspicuous rock type on the Moose



CRET
LOWER
MATTAGAMI Fm.
JURASSIC
MIDDLE
MISTUSKWIA BEDS
DEVONIAN
UPPER
LONG RAPIDS Fm.
MIDDLE
WILLIAMS ls. Fm.
MURRAY ls. Fm.
MOOSE RIVER Fm.
KWATABOAHEGAN Fm.
LOWER
STOOPING RIVER Fm.
SEXTANT Fm.
SILURIAN
UPPER
KENOGAMI RIVER Fm.
LOWER
ATTAWA-PISKAT Fm.
EKWAN RIVER Fm.
SEVERN RIVER Fm.
ORDOVICIAN
UPPER
RED HEAD RAPIDS Fm.
CHURCHILL RIVER GROUP
800
700
600
500
400
300
200
100
0
metres

Modified after Norris(1986) p.23

Figure 74.2. *Stratigraphy of the Moose River Basin. The Moose River Formation is highlighted.*

River, with the lower 0.5 m usually matrix supported. It grades upward into a clast-supported breccia with large (up to 3 m in diameter) clasts of gypsum, selenite, and limestone contained in a grey matrix. The matrix consists of fine-grained aggregates of gypsum and breccia. The lower contact with the massive gypsum unit is usually very undulatory.

On the Moose River, massive white gypsum exposures may extend 2 to 3 m below the water level, as indicated by the presence of deep pools beneath some outcrops at the shoreline. Large overhangs of gypsum can form where river water has caused the dissolution of exposed outcrop. Large solution caverns have developed along joint sets at the water level. These features are up to 1 m high and 3 to 4 m deep. The development of caverns appears to be more enhanced on the Moose River exposures, since jointing is not as well developed on the Cheepash River and Gypsum Mountain outcrops.

CHEEPASH RIVER GYPSUM EXPOSURES

Exposures of gypsum occur over a distance of approximately 9 km on the Cheepash River, commencing about 16 km upstream from the Ontario Northland Railway bridge (*see* Figure 74.1). Outcrops of gypsum are discontinuous on both sides of the river, with section thicknesses ranging from 0.5 to 12 m (average 3 m). The dominant lithological unit in these exposures is a massive snow-white gypsum with a chickenwire texture. It is typically massive and medium to finely crystalline, with banding prominent in some sections. The bands consist of either massive gypsum and/or dark brown coarsely crystalline selenite or clear selenite. Where the massive white gypsum dominates the section, the surface can be very smooth, scalloped, or rounded; the face can also be undercut by dissolution.

The massive gypsum unit in some sections is overlain by a gypsum breccia, consisting of grey fine- to medium-grained clasts of gypsum and limestone in a matrix of dark green-grey argillaceous material. The breccia unit is not as well developed on the Cheepash River as it is on the Moose River. The breccia is overlain by an impure white-brown massive gypsum, consisting of medium to finely crystalline gypsum with abundant clots and bands of argillaceous and laminated limestone.

GYPSUM MOUNTAIN

Southeast of the Moose River gypsum exposures lies an area called Gypsum Mountain. The area is less than 8 m above the level of the surrounding muskeg, but due to improved drainage in the area a varied and substantial growth of trees has developed, giving the area an appearance of a "mountain-like" setting. The area covers approximately 5 km², and can be accessed only by helicopter or boat. The gypsum here is dominantly massive, white, and medium to finely crystalline, with thin beds and laminae of brown limestone present in some sections. A gypsum breccia unit can overlie the massive gypsum unit in some outcrops. Large natural bridges of gypsum can be seen spanning the muskeg.

ECONOMIC GEOLOGY

The gypsum deposits of the Moose River Basin have been the focus of considerable interest ever since they were first described by Robert Bell in 1875. Exploration and evaluation of the gypsum outcrops had been hampered by the inaccessibility of the area in the first few decades of this century. However, with completion of the Ontario Northland Railway to Moosonee, sporadic exploration by various companies has taken place. In 1923, W. Tees Curran acquired patents on 12 claims he staked along the banks of the Moose River. In 1955, the Atlas Gypsum Corporation Limited staked 32 claims surrounding the Curran property on the north side of the Moose River. Some preliminary work was carried out, but the claims were allowed to lapse. During the fall of 1963, the Moosonee Gypsum Company carried out an 18–hole Drilling Program on the Cheepash River, to test the lateral extent of the gypsum beds. In 1985, Edward Jerome staked 16 claims in Carroll and Canfield townships on the west shore of the Moose River. No work was ever reported on the claims and they were subsequently cancelled in June of 1986.

Results from the geological mapping carried out this summer indicate that the most attractive of the gypsum deposits may be that of the Cheepash River. Geochemical analyses carried out this fall will help determine the purity of the gypsum on the Cheepash River, and in the other locations. Stratigraphic correlation of the two units between the significant exposures will be attempted.

To complement the summer field work, the Mineral Development Section of the Ministry of Northern Development and Mines, Toronto, is also undertaking an assessment of high–purity gypsum markets in North America. The results of this study should be known early next year. These results will be combined with the data from the geological study and published as an Industrial Mineral Background Paper.

ACKNOWLEDGMENTS

The author is indebted to Andrea Henry and Joel Mejilla for their able assistance during this field season. Special thanks are extended to the staff of the Ontario Ministry of Northern Development and Mines office in Timmins, and to the Ontario Ministry of Natural Resources Timmins Fire Centre, who arranged for helicopter support.

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75. Project Number 88–2. Paleozoic Geology of the Central Bruce Peninsula

D.K. Armstrong

Geologist, Paleozoic/Mesozoic Geology Subsection, Engineering and Terrain Geology Section, Ontario Geological Survey, Toronto.

INTRODUCTION

The Paleozoic strata exposed in the central portion of the Bruce Peninsula was mapped during the summer of 1988. This was the second year of a multi–year geological mapping project designed to cover the entire Bruce Peninsula. The northern portion of the Bruce Peninsula was mapped during the summer of 1987 (Armstrong 1987) and the preliminary geology map covering that area is forthcoming (Armstrong and Dubord, in preparation).

The overall objective of the Bruce Peninsula Paleozoic Mapping Project is to produce 1:50 000 scale geological maps of the Peninsula, incorporating updated stratigraphic terminology and new outcrop and subsurface information. Among other uses, these maps will aid in the delineation and evaluation of potential resources such as building and crushed stone.

Specific objectives in the 1988 field season included a) documentation of the geologic setting of building stone quarries in the map area; b) investigation of karst features such as pavements, caves, and dissolution widened joints; c) systematic measurement of joints and other structural features; d) investigation of known zinc occurrences; e) continued investigation of the relationship of the Eramosa Member with the Amabel and Guelph formations; and f) utilization of subsurface information from the Ontario Geological Survey's regional stratigraphic drillhole, OGS–82–4, drilled 6 km northwest of Wiarton in 1982 (Johnson *et al.* 1985).

LOCATION

The 1988 map area (*see* Figure 75.1) includes the central Bruce Peninsula between Latitudes 44°45′N and 45°00′N. This area is covered by 1:50 000 scale NTS map sheets of Cape Croker (41 A/14) and White Cloud Island (41 A/15). The map area can be accessed by Highway 6 via Owen Sound and Wiarton. Most of the map area is readily accessible via public and private roads and trails, and by the Bruce Trail.

GENERAL GEOLOGY

The Paleozoic units exposed on the central Bruce Peninsula are listed in the stratigraphic column in Figure 75.2. They range in age from the Upper Ordovician Georgian Bay Formation to the Middle Silurian Guelph Formation. The stratigraphic nomenclature used in this study is modified after previous investigators of Paleozoic geology on the Bruce Peninsula (Williams 1919; Caley 1945; Bolton 1953,

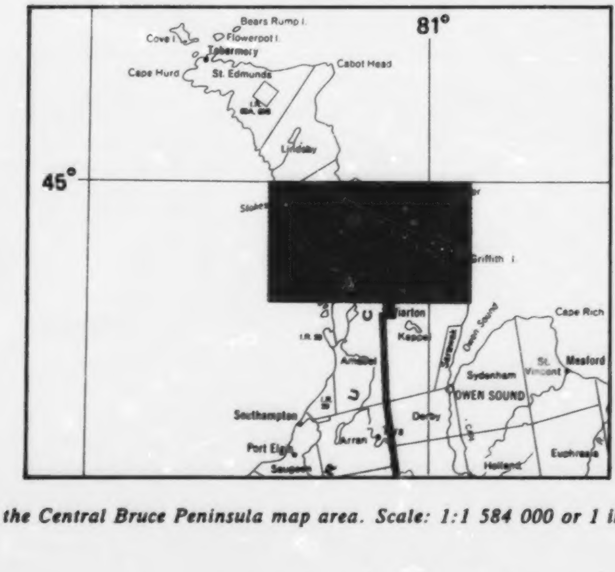

Figure 75.1. *Location of the Central Bruce Peninsula map area. Scale: 1:1 584 000 or 1 inch to 25 miles.*

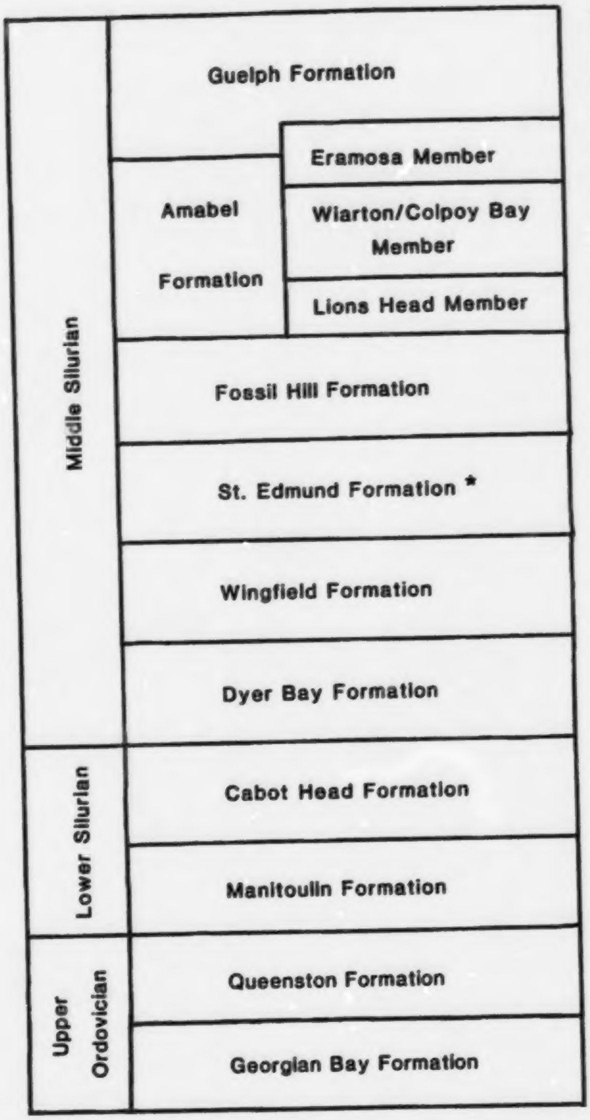

Figure 75.2. *Stratigraphic nomenclature of Paleozoic strata exposed on the central Bruce Peninsula (modified after Bolton 1957; Sanford 1969; Liberty and Bolton 1971). (Note: * not present in the map area.)*

1957; Sanford 1969; Liberty 1966; Liberty and Bolton 1971) and includes consideration of more recent mapping by the Ontario Geological Survey in the adjacent geographic areas of Manitoulin Island (Johnson and Telford 1985) and the Collingwood area (Telford 1976). Revisions in the stratigraphic column (Figure 75.2) with respect to the nomenclature used by previous workers (e.g. Liberty and Bolton 1971) are discussed in Armstrong (1987).

The white dolostone cliffs of the Amabel Formation form the Niagara Escarpment along the eastern margin of the Bruce Peninsula. The units below the Amabel Formation are exposed in a generally narrow outcrop belt beneath and east of the Escarpment. The Georgian Bay and Queenston formations are exposed on Cape Croker, a peninsula which extends to the northeast into Georgian Bay. The Amabel and Guelph formations are the most aerially extensive units on the Bruce Peninsula. These formations underlie a broad belt from the Escarpment edge in the east to Lake Huron in the west. Quaternary deposits are somewhat thicker and more significant in this map area as compared with the northern Bruce Peninsula area. Particularly significant are raised beaches and sand dunes along the west shore and drumlins in the south–central area.

1988 FIELD MAPPING

Each of the formations exposed in the central Bruce Peninsula map area is described below in ascending stratigraphic order. This report highlights significant new finds and observations.

GEORGIAN BAY FORMATION: The Georgian Bay Formation consists of interbedded limestones, dolostones, siltstones and shales which occur in a narrow outcrop belt along the northeasternmost shores of Cape Croker. This formation typically occurs in bedding plane exposures near the shoreline, however, a section with approximately 7 m of stratigraphic thickness is exposed on the southeastern shore of North Bay (UTM 500180mE, 4978460mN). This formation is approximately 100 m thick in drillhole OGS–82–4 (Johnson *et al.* 1985).

The Georgian Bay Formation is typically a grey–green shale with interbeds (termed "hardbands") of siltstone and limestone. Current structures such as flute casts and ripple laminations are common in the limestone and siltstone beds. Some of the limestone beds are very fossiliferous with abundant bryozoans, brachiopods, nautiloids, and rare corals and stromatoporoids.

QUEENSTON FORMATION: The Upper Ordovician Queenston Formation consists of grey–green and maroon–red shale with subordinate interbeds of siltstone, limestone, and dolostone. The upper contact of this formation is exposed beneath the dolostone escarpment of the Manitoulin Formation along the shores of Cape Dundas from east of Rush Cove (UTM 490140mE, 4978475mN) on the north side, around to Jackson Cove (UTM 490475mE, 4976275mN) on the south. Nowhere on the Bruce Peninsula is the entire thickness of the Queenston Formation exposed. The formation is approximately 59 m thick in drillhole OGS–82–4 (Johnson *et al.* 1985).

Strata of the Queenston Formation are exposed in a number of small outcrops on Cape Croker. Both in outcrop and in drillcore (OGS–82–4), the red shale appears to be a subordinate component. Due to the lithologic similarities between the Georgian

Bay and Queenston formations, outcrops which lack red shale are difficult to assign (i.e. at the northeast end of Cape Croker).

The Queenston Formation contains numerous sedimentary structures indicative of shallow water deposition. These include ripples, mudcracks, and burrows. Locally, in some red shale outcrops, mudcracks are grey–green.

MANITOULIN FORMATION: The Lower Silurian Manitoulin Formation is well exposed in low escarpments along the shores of Cape Dundas (UTM 490815mE, 4977830mN), Cape Paulette (UTM 491850mE, 4974250mN), and Sydney Bay (UTM 492480mE 4970825mN), on the east side of the Bruce Peninsula. In the map area, the maximum thickness of this formation in outcrop is 8 m. Its upper contact, however, is not exposed. In drillhole OGS–82–4 the Manitoulin Formation is 12.5 m thick (Johnson *et al.* 1985).

The Manitoulin Formation is a thin–bedded, light grey–brown dolostone unit which is sparsely to very fossiliferous. Chert nodules and lenses are common and the fauna is typically silicified. The formation commonly exhibits sedimentary structures such as parallel lamination, bioturbation, and locally, low angle cross–bedding. Gypsum nodules, up to 10 cm in diameter, were discovered in the lower part of this formation east of Rush Cove (UTM 490270mE, 4978485mN).

In the lower few metres of the Manitoulin Formation, the dolostone beds become more argillaceous and thin interbeds of grey–green shale occur. This suggests that the basal contact of the Lower Silurian Manitoulin Formation with the underlying Upper Ordovician Queenston Formation is lithologically gradational in this area.

CABOT HEAD, DYER BAY, AND WINGFIELD FORMATIONS: The Lower Silurian Cabot Head Formation, and Middle Silurian Dyer Bay and Wingfield formations are shale, dolostone, and shale–dominated units, respectively. The mainly dolostone St. Edmund Formation overlies the Wingfield Formation in the northern Bruce Peninsula area but does not occur in this map area.

The lowest of these units, the Cabot Head Formation, is poorly exposed in the map area. In the northern Bruce Peninsula map area, this formation is predominantly a red shale with subordinate grey–green shale beds occurring at the top and as thin interbeds. In the central Bruce Peninsula map area, it is best exposed in a road cut just above Rush Cove (UTM 487400mE, 4977900mN) where approximately 2 m of grey–green and red shales of the Cabot Head Formation directly underlie approximately 3 m of thin–bedded dolostones of the Dyer Bay Formation. The basal contact of the Cabot Head Formation is not exposed in the map area. This formation is approximately 25 m thick in drillhole OGS–82–4 (Johnson *et al.* 1985).

The Dyer Bay Formation is best exposed in the road cut above Rush Cove (UTM 487400mE, 4977900mN). Other, thinner exposures of this formation occur on Cape Croker as subordinate escarpments on the slopes below and east of Sydney Bluff (UTM 492455mE, 4973235mN), south of Kings Point Bluff (UTM 496375mE, 4968155mN), and south of Sydney Bluff (UTM 491860mE, 4970225mN). The formation is approximately 5 m thick in drillhole OGS–82–4 (Johnson *et al.* 1985).

The Dyer Bay Formation consists of very thin– to medium–bedded, light to dark grey, fine– to medium–crystalline dolostones and argillaceous dolostones. It is generally fossiliferous containing abundant bryozoans and brachiopods with fewer corals and gastropods. Sedimentary structures are abundant and include burrows, planar and ripple laminations, and soft sediment deformation features.

The Wingfield Formation consists of interbedded grey–green shale and grey to grey–brown, fine– to medium–crystalline, thin–bedded dolostone. The shaly interbeds cause this unit to weather recessively and result in poor exposures. The uppermost beds (typically less than 0.5 m thick interval) of the Wingfield Formation are commonly exposed immediately beneath escarpments of the overlying Fossil Hill Formation. The thickest exposure of the Wingfield Formation (2 m) occurs on the shore of Isthmus Bay, just north of Lion's Head (UTM 490105mE, 4982255mN). In drillhole OGS–82–4 (Johnson *et al.* 1985) the Wingfield Formation is approximately 5 m thick.

The Wingfield Formation is non–fossiliferous, however, burrows are present in some beds. The dolostone beds are locally planar– to ripple–laminated and commonly contain mudcracks and argillaceous stringers or shale lithoclasts.

FOSSIL HILL FORMATION: The Middle Silurian Fossil Hill Formation is well exposed at many localities in the map area as a subordinate escarpment beneath the main Niagara Escarpment. It is best exposed in spectacular bedding plane and small cliff outcrops along the shores of Isthmus Bay (UTM 480100mE, 4982230mN), north of Lion's Head. Other good exposures of the Fossil Hill Formation include escarpments at Barrow Bay (UTM 482050mE, 4978290mN), on the road into Hope Bay (UTM 487135mE, 4971830mN), south of Sydney Bay (UTM 493560mE, 4969945mN), and the escarpment which trends from the southwest end of Jones Bluff (UTM 494375mE, 4969210mN) through Coveney's Hill (UTM 494850mE, 4967570mN) to Malcolm Bluff (UTM 495690mE, 4967180mN to UTM 497250mE, 4966565mN). The thickest exposed interval of the Fossil Hill Formation is the 7 m thick escarpment south of Sydney Bay (UTM 493560mE, 4969945mN). In drillhole OGS–82–4, 17 km to the southwest, the Fossil Hill

Formation is less than 4 m thick (Johnson *et al.* 1985).

The Fossil Hill Formation consists of very fossiliferous, fine– to coarse–crystalline, light tan–brown to brown, thin– to medium–bedded dolostone. Chert is common as thin nodules or lenses. The fauna, which is typically silicified, is dominated by pentamerid brachiopods, however, a variety of corals and stromatoporoids are also plentiful. The paleontology of the Fossil Hill Formation is documented by Johnson (1979).

A non–fossiliferous, bioturbated, very fine– to fine–crystalline dolostone interval occurs in the middle to lower portion of the Fossil Hill Formation. This "barren zone" thins from a thickness of approximately 2 m at Isthmus Bay to less than 20 cm at Cape Croker. The base of this "barren zone" typically occurs about 1 m above the base of the formation.

AMABEL FORMATION: The Amabel Formation is formally subdivided into three members (Figure 75.2), however, recent geological investigations on the Bruce Peninsula (Armstrong and Meadows 1988; Armstrong and Dubord, in preparation) have indicated that the uppermost of these, the Eramosa Member, may in fact be more closely associated with the overlying Guelph Formation. This uncertainty in the stratigraphic placement of the Eramosa Member is indicated in Figure 75.2 and the Eramosa Member unit is discussed separately below.

Excluding the Eramosa Member, the Amabel Formation consists of three lithofacies which comprise two members, the Lions Head and the Wiarton/Colpoy Bay members. In drillhole OGS–82–4, these two members total approximately 25 m in thickness (Johnson *et al.* 1985).

The first Amabel Formation lithofacies A constitutes the Lions Head Member and is a thin– to thick–bedded, fine– to medium–crystalline, light tan to light grey–tan, variably mottled (typically purple–red mottles), sparsely fossiliferous dolostone. It typically exhibits flaggy to blocky parting, locally contains silicified fossils (commonly corals) and chert nodules, and has local minor wispy microstylolites. The lower contact of the Lions Head Member, and of the Amabel Formation, with the underlying Fossil Hill Formation was only discovered at two locations in the map area: at the western end of Kings Point Bluff (UTM 495890mE, 4968275mN); and at Malcolm Bluff (UTM 497250mE, 4966565mN). The contact is sharp with a dramatic decrease in fossil and chert content and the appearance of mottles in the Lions Head Member. However, the matrix dolomite of both the Fossil Hill Formation and the Lions Head Member appear macroscopically similar.

The Wiarton/Colpoy Bay Member of the Amabel Formation consists of two lithofacies: B the non–biohermal; and C, the biohermal/biostromal. These are both typically thick– to massive–bedded, planar to undulatory parted, light grey to light grey–tan, variably mottled (typically blue–grey mottles), medium– to coarse–crystalline dolostones. The non–biohermal lithofacies B is sparsely to moderately fossiliferous with crinoids predominating. A variety of other fossil types are also present, including corals, bryozoans, brachiopods, pelecypods, and rare gastropods and trilobites. Another characteristic of this lithofacies is the fine ribbing exhibited on weathered faces oriented perpendicular to bedding. The ribs are commonly 5 to 10 cm apart and are thought to be related to original bedding. Locally, the geometry of this ribbing suggests cross–bedding. Lithofacies B is thought to constitute most of the Wiarton/Colpoy Bay Member and the Amabel Formation in this map area.

The biohermal/biostromal lithofacies C of the Wiarton/Colpoy Bay Member differs from lithofacies B in the abundance and type of fossils present. Although crinoids still dominate, frame–building organisms, such as large (up to 0.5 m diameter) coral heads and bryozoans become more significant. The lack of distinct flanking beds makes it difficult to discern whether this lithofacies is biostromal or biohermal. Generally, lithofacies C appears to occur towards the top of the Amabel Formation interval.

ERAMOSA MEMBER: Bituminous, thin–bedded dolostone beds occurring in the vicinity of the Guelph/Amabel Formational contact have previously been assigned to the Eramosa Member of the Amabel Formation (Bolton 1957; Liberty and Bolton 1971). A recent investigation of the Eramosa Member on the Bruce Peninsula (Armstrong and Meadows 1988) recognized that the Eramosa strata is contained within (i.e. interbedded with) Guelph Formation strata indicating that the Eramosa Member should perhaps be reassigned to the Guelph Formation. This is supported by regional mapping in the northern Bruce Peninsula (Armstrong 1987; Armstrong and Dubord, in preparation) which identified strata with Eramosa–type characteristics (i.e. bituminous, thin–bedded and laminated) occurring well up into the Guelph Formation interval. Formal reassignment of this unit to the Guelph Formation must await completion of the Bruce Peninsula mapping project and comparisons with the Eramosa Member exposed elsewhere in southern Ontario.

Armstrong and Meadows (1988) identified four lithofacies in the Eramosa Member. Their Eramosa lithofacies 1A and 1B are both laminated and contain abundant planar microstylolites, however, 1B is darker in colour and more bituminous. Their Eramosa lithofacies 2 is light tan–brown to grey–brown, non–laminated, very slightly bituminous dolostone (very similar to Guelph Formation lithofacies B described below), and their Eramosa lithofacies 3 is bituminous, light to dark brown, with abundant microstylolites. Eramosa lithofacies 3 is thought to be transitional between the laminated lithofacies 1A and 1B and lithofacies 2. In addition to the Eramosa Member lithofacies identified by Armstrong and Meadows (1988), a fifth Eramosa lithofacies, lithofacies 4, is identified in this study as thin to thick, bituminous, coral– and stromatoporoid–rich biostromal dolostone beds.

Liberty and Bolton (1971) designated the road cut at the south end of Sky Lake (UTM 479940mE, 4960130mN) as the reference section for the Eramosa Member on the Bruce Peninsula. This section is approximately 10 m thick and consists of interbedded Eramosa lithofacies 3, 1B and 4 (in order of abundance). Similar, but thinner sequences were discovered to the northwest along the western shore of Sky Lake (UTM 479480mE, 4960625mN) and at the southwest end of Beattie Lake (UTM 478200mE, 4963365mN). Eramosa lithofacies 3, with local minor 1B, also occurs in the northwest portion of the map area along the northern and eastern shores of Stokes Bay, around Look About Bay (UTM 471475mE, 4977515mN), and at the east end of Pike Bay (UTM 474800mE, 4968700mN). At the last locality, chert occurs as small nodules and as rare silicified fossils.

Along the eastern shore of Stokes Bay (UTM 470710mE, 4981800mN) Eramosa lithofacies 3 is a limestone. This is the only known occurrence of limestone in the entire Middle Silurian sequence on the Bruce Peninsula. Elsewhere in the Stokes Bay and Look About Bay areas, the dolostone of lithofacies 3 is only slightly calcareous.

The Eramosa Member lithofacies 1A is exposed along the southern boundary of the map sheet in an arcuate belt which includes the Ebel, Owen Sound Ledgerock, and Amlan (formerly Ross) quarries and continues to the west almost to Isaac Lake (from UTM 486300mE, 4955200mN to UTM 482480mE, 4956860mN).

In the southern portion of the map area, Eramosa–type lithofacies 1A also occurs less than 750 m north of the inactive Cook Quarry (UTM 485535mE, 4956065mN; and 486075mE, 4956375mN), on the west side of the hill north of Wiarton (UTM 488360mE, 4955175mN and vicinity), and on the top of the upper road cut immediately north of Wiarton (UTM 488775mE, 4955350mN).

In the central portion of the map area, Eramosa–type lithofacies 1A beds occur in elongate domes overlying biohermal ridges which are tentatively assigned to the Guelph Formation. This area extends from the McLay Quarry on the east side of Highway 6 (UTM 481400mE, 4968500mN), west to the presently inactive Bruce Marble and Stone Quarry (UTM 479230mE, 4968310mN). Beds of Eramosa–type lithofacies 1A were also discovered just northwest of Beattie Lake (UTM 479040mE, 4964570mN).

It is apparent from these occurrences of the Eramosa–type lithofacies and those in the northern Bruce Peninsula (Armstrong and Dubord, in preparation), that Eramosa–type lithofacies may occur at various stratigraphic levels in the Guelph Formation interval.

GUELPH FORMATION: The Middlé Silurian Guelph Formation is the highest stratigraphic unit exposed in the central Bruce Peninsula map area. It has not previously been subdivided into formal members on the Bruce Peninsula, however, three main lithofacies have been recognized in this study.

The dominant Guelph Formation lithofacies A consists of thin– to thick–bedded, fine– to medium–crystalline, light grey–tan to tan, sparsely to moderately fossiliferous dolostone. The fossil assemblage in lithofacies A is varied and includes gastropods, brachiopods, crinoids, cephalopods, and pelecypods. Guelph Formation lithofacies B is a thin– to thick–bedded, fine–crystalline, light tan to light brown, slightly bituminous, sparsely fossiliferous dolostone with brown microstylolite swarms or bands. Guelph lithofacies B is lithologically gradational with lithofacies of the Eramosa Member (described above).

The biohermal/biostromal Guelph Formation lithofacies C consists of medium– to thick–bedded, fine– to coarse–crystalline, light grey–tan to light creamy tan, variably mottled, sparsely to very fossiliferous dolostone. The variety of fossil types in this lithofacies is similar to that of lithofacies A, except they tend to be more abundant and larger in lithofacies C. Locally, large crinoid columnals predominate and large coral heads (up to 0.75 m in diameter) are diagnostic. In some cases, the preponderance of frame–building organisms and adjacent sub–horizontal (flanking?) beds of lithofacies A or B indicate that lithofacies C is biohermal.

Three types of Guelph Formation bioherms or biostromes are recognized in the central Bruce Peninsula map area. The first type are small (less than approximately 3 m diameter) mounds or domes which occur on the western shore of the Peninsula. These are typically stromatolitic or stromatoporoidal, but may also contain corals, bryozoans, brachiopods, gastropods, and cephalopods.

The second type of organic build–up in the Guelph Formation are biohermal ridges, typically oriented northwest–southeast, in the order of 10 to 20 m wide by 100 m long, and with very well developed flanking or draping beds. These bioherms are most abundant in the central portion of the map area where a zone or "swarm" of them crosses Highway 6 (UTM 481140mE, 4968750mN) approximately 11.5 km south of Ferndale. At this locality, the biohermal ridges are readily recognizable both on the 1:50 000 scale topography map (NTS 41 A/14) and on 1:10 000 scale aerial photographs. West of Highway 6, this biohermal ridge zone continues to the north in a zone from 1.5 to 5 km west of the highway up to at least Spry, 7.5 km southwest of Ferndale. These ridges are overlain by Guelph lithofacies A and B beds to the west. East of Highway 6, the biohermal ridge zone continues for up to 5 km and appears in another zone south of Albemarle Brook to north of Berford Lake.

The third type of Guelph Formation bioherms cover very large areas (up to 1 by 3 km) and locally trend approximately northeast–southwest (may be glacially modified). A good example of this type of bioherm occurs approximately 4 km southwest of Ferndale (UTM 476500mE, 4977900mN). A large biohermal zone south and west of Berford Lake may also be of this type. These large bioherms may simply be composites of the second type of Guelph bioherm.

The Guelph Formation biohermal lithofacies C and Amabel Formation biohermal lithofacies C are similar in many respects: bedding thickness, colour, mottling, crystal size, faunal abundance and type. The best criteria for distinguishing between the two are the presence and lithofacies type of associated flanking beds.

ECONOMIC GEOLOGY

Quarrying has been an important part of the Bruce Peninsula economy since the turn of the century. A number of dolostone units, including the Manitoulin, Amabel and Guelph formations, have been quarried for building stone, aggregate, and lime. Currently, the Eramosa Member and the Wiarton/Colpoy Bay Member are quarried for building stone in the central and southern portion of the Bruce Peninsula. In addition, the Wiarton/Colpoy Bay Member and the Manitoulin Formation are quarried for aggregate in the Owen Sound area. Although the Guelph Formation is quarried in southern Ontario for lime and construction aggregate, it remains an untested potential resource on the Bruce Peninsula.

In the central Bruce Peninsula map area, there are four quarries actively excavating the Eramosa Member for a variety of building stone products, including landscaping and dimension stone. There are also at least three inactive or abandoned Eramosa quarries. A new quarry, the McLay Quarry, began operation this past summer in lot 5, concession III East, in Albemarle Township (UTM 481400mE, 4968500mN). This quarry is extracting thin–bedded Eramosa Member lithofacies 1A dolostone for flagstone. The Bruce Marble and Stone Quarry in lot 3, concession I East of the same township (UTM 479230mE, 4968310mN) ceased operation in 1987.

The west side of the Ross Quarry in lot 11, concession XXV of Amabel Township (UTM 484550mE, 4956600mN) was purchased by Amlan Landscaping Ltd. in 1987 and is now operating under that name.

Adair Marble Quarries, a division of Arriscraft Corp., is excavating mill blocks from the Wiarton/Colpoy Bay Member of the Amabel Formation in lots 7 and 8, concession VIII in Albemarle Township (UTM 487200mE, 4969350mN). This past summer, this company expanded operations across the road from the main quarry into lot 7, concession IX.

The Wiarton/Colpoy Bay Member exposed in the Adair quarries is dominantly typical Amabel lithofacies B, with minor small zones of dominantly blue, more fossiliferous, harder and more brittle dolostone. A light tan variety of lithofacies B with microstylolite swarms is exposed in the northwestern part of the main quarry and is termed "sepia" by the quarry operator.

A number of zinc occurrences are known on the Bruce Peninsula and have been the subject of periodic exploration activity since early this century (Guillet 1967) and a number of academic investigations (eg. Sangster and Liberty 1971; Tworo 1985). The Bruce Peninsula Zinc or Albemarle Zinc Property (Ontario Geological Survey, Assessment Files Research Office, Mineral Deposit Inventory #SO0666), now owned by R. Pasarich of Owen Sound, is located in lot 30, concession III East (UTM 485115mE, 4958800mN). On this property, sphalerite, largely examined from material excavated out of old trenches, mainly occurs in–filling and replacing fossils. The mineralization at this property, and in the vicinity, occurs in the Guelph Formation biohermal lithofacies C which appears to constitute a large biohermal zone south and west of Berford Lake.

Zinc mineralization has also been reported (Liberty and Bolton 1971) in lots 4 and 5, concession III East of Albemarle Township on the McLay Quarry property (UTM 481400mE, 4968500mN). Here, sphalerite occurs in Eramosa Member lithofacies 1A as small coarse–crystalline nodules surrounded by haloes of fine–crystalline sphalerite replacing the dolomite matrix. At the north end of the Owen Sound Ledgerock Wiarton Quarry (UTM 484900mE, 4955200mN), sphalerite occurs as small nodules and small fracture fillings, also in Eramosa Member lithofacies 1A. At both of these occurrences, a white hydrozincite weathering halo is developed around the sphalerite mineralization.

STRUCTURAL GEOLOGY AND KARST

During field mapping, an effort was made to systematically document all structural features. This was done in part to evaluate the tectonic model for southern Ontario hypothesized by Sanford *et al.* (1985) and to investigate the association of these structures to karst development, zinc mineralization, oil and gas migration and entrapment, and regional hydrogeology of the Bruce Peninsula area.

Beds with non–horizontal dips are common and are generally related, by either differential compaction or off–lapping, to nearby biohermal development. In some cases, such as at the upper road cut immediately north of Wiarton (UTM 488775mE, 4955350mN), the bioherm is not evident (probably eroded).

Neotectonic structures (i.e. pop–ups) were observed in the Owen Sound Ledgerock Wiarton Quarry and in the Adair Marble Quarry. Pop–ups were also discovered in the thinly interbedded shales, siltstones and limestones of the Queenston Formation west of Benjamin Point (UTM 497440mE, 4979170mN) on Cape Croker and in the Fossil Hill Formation southwest of Cape Croker (UTM 495265mE, 4966040mN).

No structural features were discovered in the vicinity of zinc mineralization. More detailed mapping of these prospects, however, is required to adequately investigate potential structural controls on mineralization.

Karst features on the Bruce Peninsula were the subject of an investigation by Cowell (1976) and subsequent publication by Cowell and Ford (1980). During this past field season, systematic documentation was undertaken of various karst features which include pavements, dissolution widened joints, and caves. Karst pavements vary from pitting which is well developed on beds of fossiliferous dolostones of Guelph Formation lithofacies A, best exposed along the west side of the Peninsula, to runnels which are common on tops of fluted outcrops of either Guelph or Amabel formations in the central and eastern part of the Peninsula.

The most obvious structures observed on the Bruce are dissolution widened or enhanced joints. The orientation, opening width, dissolution evidence, regularity of spacing and pattern, and persistance or length of joints were systematically documented. Dissolution widened joints are typically wider opened and deeper on the eastern and topographically higher side of the Bruce Peninsula. Generally, dissolution widened joints are open from 10 to 20 cm. Within the first tens of metres back from the Escarpment face, joint openings of up to 1 m (UTM 496200mE, 4967140mN) suggest that stress release is locally significant in opening joints.

Within a zone 1 to 2 km back from the Escarpment face, joint patterns are recognizable on 1:10 000 scale aerial photographs in open fields with thin overburden cover. These joint patterns occur in fields underlain by either the Amabel or Fossil Hill formations and are particularly evident in the area just southwest of Cape Croker.

Excavations at the Adair Marble Quarry (UTM 487200mE, 4969350mN) near Hope Bay have enabled examination of the depth of dissolution in joints. In areas of the quarry which were exposed as outcrops before excavation, dissolution widened joints (5 to 10 cm open) extend down less than 4 m from the surface. Below this, the joints are almost closed, they exhibit little evidence of dissolution, and are commonly cemented with calcite. In areas of the quarry which were covered by overburden prior to excavation, dissolution along joints appears to be minimal.

The Mar Caves, located on the northwestern side of Berford Lake (UTM 484775mE, 4961775mN), are dissolution caves which were developed in sinkhole–like structures in biohermal lithofacies C of the Guelph Formation. Joints appear to have partially controlled the development of these caves (Cowell 1976). Grieg's Caves, a popular tourist attraction located on the southern side of Barrow Bay (UTM 488800mE, 4977750mN), are "sea caves" (Cowell 1976) developed near the base of the Amabel Formation during a higher lake level. Although formed primarily by wave action, joint controlled dissolution has also played a role (Cowell 1976). Sea caves are common along the Escarpment at various elevations (Cowell 1976).

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76. Project Number 88–36. Detailed Structural Geology Investigations of Prince Edward County, Southern Ontario.

G.H. McFall[1], Owen L. White[2], and A. Allam[3]

[1]Geologist, Paleozoic/Mesozoic Geology Subsection, Engineering and Terrain Geology Section, Ontario Geological Survey, Toronto.

[2]Chief, Engineering and Terrain Geology Section, Ontario Geological Survey, Toronto.

[3]Geophysicist, Paleozoic/Mesozoic Geology Subsection, Engineering and Terrain Geology Section, Ontario Geological Survey, Toronto.

INTRODUCTION

Detailed mapping of the structural features in the southern part of Prince Edward County has been undertaken by the Ontario Geological Survey as its contribution to a multi–year program investigating neotectonics in eastern Canada. This research is being coordinated by the Multi–Agency Group for Neotectonics in Eastern Canada (MAGNEC). Other member agencies involved in the MAGNEC projects in Ontario include: Atomic Energy Control Board, Geological Survey of Canada, Ontario Centre for Remote Sensing, Ontario Ministry of Natural Resources, and Ontario Hydro.

The Ontario Geological Survey's contribution to this research is centred on the field identification of geological features which may indicate neotectonic movement, particularly features that can be clearly demonstrated to have occurred since deglaciation (approximately 10 000 years ago in the Prince Edward County area). In bedrock, these features include faults, stress relief features (pop–ups), domes, and off–set strata along adjacent bedding planes.

Activities in 1988 were concentrated in the southern part of Prince Edward County in Athol and South Marysburgh townships (Figure 76.1). Located south of the town of Belleville, the study area encompassed approximately 100 km² and is bounded

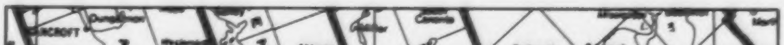

Figure 76.1. *Location map for Prince Edward County. Scale: 1:1 584 000 or 1 inch to 25 miles.*

by the Lake Ontario shoreline, Latitude 43°56′N, Longitude 77°12′ and Longitude 77°03′W. In addition to detailed field mapping, activities this year included the drilling of two boreholes into the largest stress relief feature (pop–up) in the region, and detailed geophysical surveys over selected structural features. Resource assistance for this work was supplied by Ontario Hydro, University of Waterloo, the Tweed office of the Resident Geologist, Ontario Ministry of Northern Development and Mines, and the Napanee District office of the Ontario Ministry of Natural Resources.

GENERAL GEOLOGY

Paleozoic strata exposed in the southern part of Prince Edward County are the Middle Ordovician Verulam and Lindsay formations. These overlie the Ordovician Bobcaygeon and Gull River formations (Simcoe Group), which in turn overlie Precambrian basement rocks (Grenville Province). At some locations, a thin veneer of clastic material separates the Paleozoic from the Precambrian rocks. Total Paleozoic cover in the Belleville area amounts to approximately 210 m (Carson 1981). Regional mapping of the area by Carson (1981) suggested that the Paleozoic stratigraphy was relatively simple. Detailed mapping was subsequently undertaken in adjacent eastern Ontario, east of the Frontenac Axis (Williams, in preparation). This work included a redefinition of the Bobcaygeon/Gull River Formation contact and suggested that Carson's (1981) interpretation of the Paleozoic stratigraphy in the Belleville area required further revision.

The Verulam Formation, as most recently defined by Williams (in preparation), consists of an interbedded microcrystalline to coarse–crystalline limestone with up to 15 cm thick interbeds of dark grey calcareous shale. The Lindsay Formation, as recently defined by Russell and Telford (1983), has two members. There is a lower unnamed member consisting of microcrystalline to coarse–crystalline fossiliferous limestone with undulating shaly partings, and an upper member termed the Collingwood which is a black to dark brown, calcareous, organic–rich shale and limestone unit. The Collingwood Member has not yet been identified within the study area.

DRILLING PROGRAM

A limited drilling program was initiated prior to the field investigations. Two boreholes, located near UTM 4859360mN 332120mE, were drilled on the largest stress relief feature (pop–up) in the study area. This feature, informally named the East Duck Pond pop–up, trends northwestwards from UTM 4859200mN 332500mE to UTM 4859500mN 331800mE. The locations of the boreholes were chosen for three reasons: first, to test the subsurface configuration of the structure and the possibility of an axial fault; second, to examine the stratigraphy; and third, to obtain samples for experimental stress testing.

The first borehole was drilled to a depth of 59.5 m (195 feet) with complete recovery of the core. Breakdown of the drilling equipment resulted in the abandonment of the second borehole at 3.9 m (13 feet). The core from these two boreholes is presently stored in the Drill Core Library at Tweed, Ontario. Arrangements to view the core can be made through the Resident Geologist's Office, Ministry of Northern Development and Mines, P.O. Box 70, Tweed, Ontario, K0K 3J0.

GEOPHYSICAL SURVEYS

Many of the bedrock structural features scattered throughout the study area are partially blanketed by Quaternary deposits making direct observation difficult. Several obscured structural features were examined using single and twelve channel refraction seismic surveys and resistivity exploration. Five individual structural features and two areas were examined. These included three potential fault zones and three stress relief features (pop–ups). Surveys were conducted on a scale compatible with the size of the feature.

In addition, two of the regional features were examined in detail: the extension of the Picton fault (Liberty 1960) that trends northeasterly through the western part of the study area, and the Eastern Duck Pond pop–up. A series of refraction seismic surveys and resistivity exploration were conducted across each of the features at three locations in order to test for changes in the configuration of the bedrock structure.

FIELD MAPPING

The best exposures of the Paleozoic bedrock in the study area occur along the Lake Ontario shoreline. These exposures are naturally occurring and exhibit little influence of, or disturbance by, man's activities. A stereographic examination of airphotographs of the shoreline regions of Prince Edward County was conducted by Creasy (1976) who identified a number of unusual structural features. Detailed mapping of the bedding attitudes, joints, and fracture systems was carried out in order to evaluate the regional structural framework and the structures identified by Creasy. Man–made exposures, such as abandoned pits or quarries, excavated cattle ponds, road–cuts, and bulldozer–cleared bedrock outcrops were also examined in detail.

Over 250 features, identified from infrared airphotographs and previous mapping (Creasy 1976; Liberty 1960), were examined. Eight probable pop–ups, three of which were confirmed by bedrock exposures, were identified by field checking. Numerous dissolution features were also identified including open fractures (grikes) and possible sink holes. Not all of the open fractures appear to have been formed by dissolution alone but may have opened in response to changes in regional stress. There are also indications of the presence of small scale faults in the study area.

Several stress relief features (pop–ups) were excavated to expose the flanks and axis and to observe the nature of the Quaternary cover across these features. The axis of these features were clearly defined by opposing dips of bedrock layers, gaping of the bedrock, and the presence of calcite veins.

South of the western duck pond (UTM 4857900mN 328820mE), a glacially polished area abuts unpolished bedrock across a lineament identified on airphotographs. The unpolished outcrop occurs at a higher elevation than the adjacent polished part. This suggests the presence of a post–glacial fault. Excavation of the contact confirmed that 1) a fracture was present; 2) the bedding was indeed discontinuous across the feature; and 3) there were lenses of grainy, weathered calcite present in the fracture zone.

The presence of neotectonic features in southern Ontario has important implications for the construction of environmentally sensitive structures such as nuclear power developments, toxic waste storage facilities, and pipelines. A clear understanding of these features, the stresses which formed them, and how they will act in the future will permit an accurate assessment of these potential construction hazards.

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Geophysics/Geochemistry Programs

77. Summary of Activities 1988, Geophysics/Geochemistry Section

R.B. Barlow

Section Chief, Geophysics/Geochemistry Section, Ontario Geological Survey, Toronto.

GEOPHYSICAL PROGRAM

During the 1988 field season, a project to research the potential for detecting and tracing conductive strata in Precambrian rocks under thick Huronian sediments continued (Hanneson and Huxter, this volume). Approximately 110 km of gravity and 80 km of transient electromagnetic coverage was completed at 50 m intervals near the town of Cobalt, Ontario. A further 120 km of transient electromagnetic data and 8 km of EM sounding experiments are planned for the Fall and Winter months. Field surveying on this project followed extensive computer modeling and field orientation so as to optimize surveying parameters and procedures. This project is funded under the Canada/Ontario 1985 Mineral Development Agreement (COMDA), a subsidiary aggreement to the Economic and Regional Development Aggrement (ERDA) signed by the governments of Canada and Ontario.

Gravity profiling was carried out during the fall (1987) and winter (1988) months by staff of the Geophysics/Geochemistry Section along planned seismic reflection transects which were completed as part of two major Lithoprobe projects (Barlow and Wadge, *this volume*). Over 1850 gravity stations were established with a station spacing of 200 m on seismic traverse lines located along highways and lumber and forest access roads within three areas. Profiles and digital data resulting from the field work will be released during the winter of 1989.

A compilation of reconnaissance scale gravity and magnetic data in the Province together with a summary of the major potential field geophysical anomalies began and will be completed over the next few years. This work is being undertaken in co-operation with the Geological Survey of Canada. The generation of gridded information at a smaller interval will improve the high frequency content of the information as well as provide a future data base for the production of colour maps for special studies.

An interpretation of recent gravity data acquired over the Archean mafic to ultramafic intrusions in the Lac des Iles area, approximately 80 km northwest of Thunder Bay has been completed. Gravity models over the main intrusion (mean density 3.13 g/cm^3) and the Tib Gabbro (mean density 2.97 g/cm^3) show these bodies to be shallow features with depth extents ranging between 3 to 5 km. The intrusions of the Lac des Iles area appear, from the results, to represent emplacements by discrete pulses of mantle–derived magma.

Two airborne electromagnetic–magnetic surveys, covering areas of high mineral potential, were completed in 1988 (Barlow, this volume). A survey of approximately 44 000 line km in the Tashota–Geraldton–Long Lac area as well as a survey of approximately 36 000 line km in the Detour–Burntbush–Abitibi area will be released in the spring of 1989.

GEOCHEMISTRY PROGRAM

The fifth and final year of a reconnaissance till sampling project, carried out in co–operation with the Engineering and Terrain Geology Section as part of the BRIM program, will continue until March 1989 (Steele, this volume). Clastic sections of the core are subjected to heavy mineral separation so that independent gold grains may be counted and examined for their size and shape to help in determining their provenance. Quaternary stratigraphy and till geochemistry data collected in 1987 and 1988 will be released in standard formats followed by a summary report in the near future.

During July and August 1988, the remaining lake sediment and water sampling (947 samples) required for a regional geochemical survey of the Batchawana Greenstone Belt was completed (Fortescue, this volume). This represents the second phase of a three–year project carried out as part of the Canada/Ontario 1985 Mineral Development Agreement (COMDA). The purpose of the regional geochemical survey is to provide geochemical information which is of direct importance to exploration in the Batchawana Greenstone Belt. This is done either by confirming and, possibly, extending areas of known mineralization, or by indicating new areas within which mineralization may occur.

A program to verify positive geochemical results obtained in 1987 during a regional lake sediment geochemical survey in the Goudreau Lake area was completed in March 1988 (Fortescue, this volume). The verification procedure is based on the geochemistry of segments of long lake sediment cores which extend from the surficial sediment at the bottom of the lake into the mineral matter below the zone of organic matter. Experience indicated that the distribution of an element in a long lake sediment core was usually relatively uniform from 25 cm below the bottom of the lake to a metre depth or further. It was reasoned that long cores taken at the same sample points as those found to have positive geochemistry in the regional survey would provide a basis for verification of the regional survey results.

During September 1988, a small–scale regional geochemical survey based on lake sediments and waters was completed in a 400 km^2 area in the vicinity of the Magpie River situated 30 km north of Wawa, Ontario (Fortescue and Nakashima, this volume). The purpose of regional geochemical surveys of this type is to provide verified geochemical information which is of direct importance in mineral exploration. The Magpie River area is of particular interest at this time because it lies to the west of the Goudreau Lake area in which new gold deposits are currently being developed. The geochemical survey of the Magpie River area is important because parts of the area are covered by surficial deposits where outcrops of bedrock are relatively rare. Like the Goudreau Lake geochemical survey which was completed last year, the Magpie River survey can be considered as part of an orientation survey for regional geochemical coverage of the entire Wawa Greenstone Belt at some future time.

78. Project Numbers 88–26 and 88–29. Recent Airborne Electromagnetic–Magnetic Surveys in Northern Ontario

R.B. Barlow

Section Chief, Geophysics/Geochemistry Section, Ontario Geological Survey, Toronto.

INTRODUCTION

The field survey portions of two Airborne surveys were completed during 1988. In all, approximately 81 500 line km of electromagnetic and magnetic survey data were acquired during the year. The results of these surveys, which were carried out over two areas (Detour–Burntbush–Abitibi Area, Figure 78.1A, and Tashota–Geraldton–Long Lac Area, Figure 78.1B), will be released in the spring of 1989.

On March 10, 1987, the Ministry of Northern Development and Mines announced a new $10 million, five–year Airborne Geophysical Survey Program for Northern Ontario. The airborne survey program is being financed through the Northern Development Fund and managed by the Ontario Geological Survey.

To date, approximately 51 000 line km of data have been acquired, compiled, and released over two areas centred on the northern municipalities of Timmins (Figure 78.1C) and Wawa (Figure 78.1D). These surveys were released during March and May of 1988, respectively (Ontario Geological Survey 1988a, 1988b).

SURVEY INSTRUMENTATION

The GEOTEM(R) system, owned and operated by Geoterrex Limited of Ottawa, was used to acquire the electromagnetic data over the Detour–Burntbush–Abitibi area. The survey platform was a CASA C212–200, twin turboprop short takeoff and landing (STOL) aircraft having a six–strand, three–turn, horizontal transmitter loop installed around the extremities of the plane and a sensor mounted in a towed bird. A Scintrex single–cell, split–beam, cesium vapor magnetometer was mounted in a stinger on the tail of the aircraft. Instrument configuration within the craft consisted of the digital receiver and transmitter circuits, a microprocessor and tape drive for data storage, as well as the magnetometer console and positioning equipment.

The primary electromagnetic field about the aircraft is created by a series of discontinuous sinusoidal (half sine) current pulses which are fed through a three–turn loop. The duty cycle is composed of 1050 microseconds of "on time" followed by 2280 microseconds of "off time" which is utilized to sample the resulting transient produced by the ground response. During the "on time", the peak current through the loop is 600A resulting in a dipole moment of 4.5×10^5 Am^2. The receiver sensor coil is mounted vertically, with the axis in the direc-

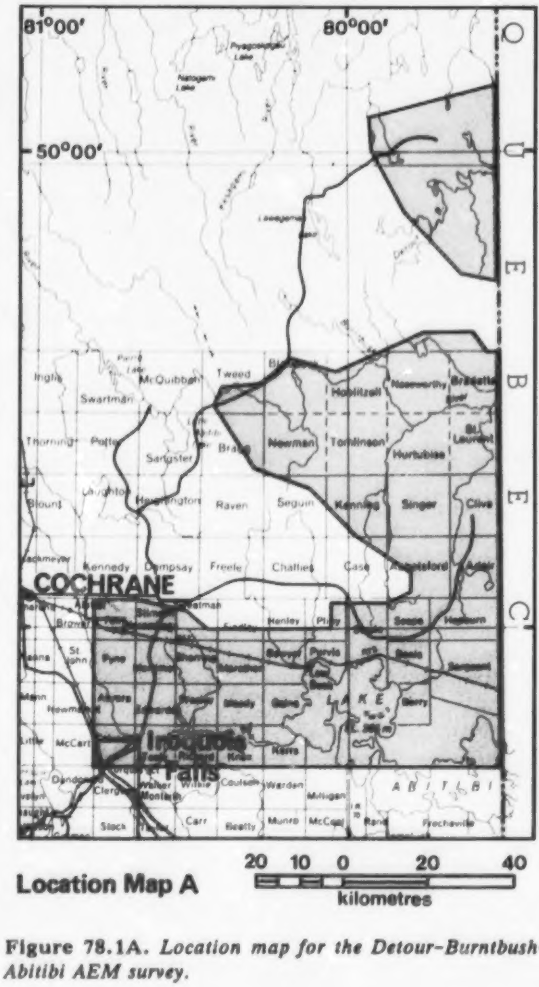


Figure 78.1A. *Location map for the Detour–Burntbush–Abitibi AEM survey.*

This project is part of the five year 1987 Airborne Geophysical Survey Program for Norhtern Ontario which is funded by the Northern Development Fund.

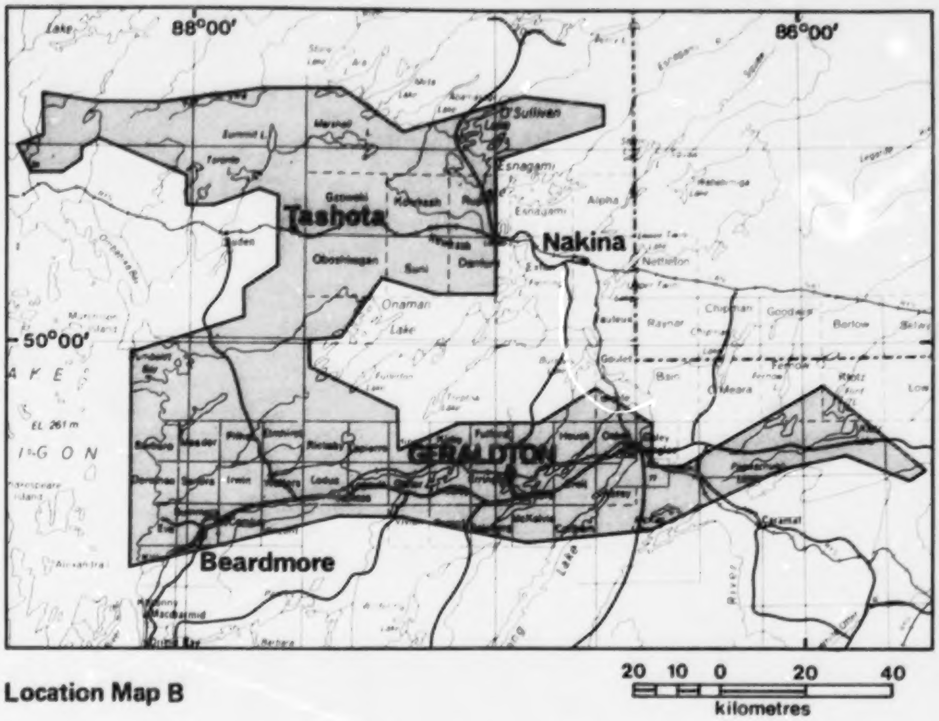


Figure 78.1B. *Location map for the Tashota–Geraldton–Long Lac AEM survey.*

tion of flight in a bird towed on a 135 m cable approximately 40 m above the ground when the aircraft survey altitude is 120 m.

The transient resulting from the ground response is sampled six times a second over twelve gates whose centres and gate widths can be software selected over the entire range of "off time". Post–flight processing normally reduced the noise level to about a 20 ppm envelope.

The AERODAT system, owned and operated by Aerodat Limited, was used to acquire the electromagnetic and magnetic data over the Tashota–Geraldton–Long Lac area. The survey platforms consisted of two aerospatiale AS 350B helicopters. Both the transmitter and receiver coils are mounted in a tubular bird which is towed below the helicopter, approximately 30 m above the ground. A Scintrex single–cell, split–beam, cesium vapor magnetometer was towed below the helicopter and above the EM bird approximately 40 m above the ground. Each Tx–Rx coil pair is separated by a 7 m distance. The coil orientations consist of two coaxial (horizontal dipole) and two coplanar (vertical dipole) coil–pairs operating at 935 and 4600 Hz and 4175 and 33 000 Hz, respectively.

Inphase and quadrature responses are measured with a resolution of better than 0.1 ppm with an electronic time constant of 0.1 second and a sampling rate of 10 readings per second. The moment of the coaxial transmitters is about 130 Am^2 and the 4175 and 33 000 Hz coplanar transmitters are 50 Am^2 and 20 Am^2, respectively. The noise level, excluding spherics, is less than 1 ppm under normal survey conditions. The instrument configuration within the helicopter consists of receiver and transmitter consoles, a digital data acquisition system, magnetometer console, and various position equipment.

The primary electromagnetic field about the bird is created by a continuous sinusoidal wave form, and the secondary field is measured in the presence of the primary field by a phase component measuring system. The intensities of the inphase and quadrature components of the secondary field are measured continuously during flight at pre–described frequencies and coil orientations and are given as fractions of the primary field strength. The effective exploration depth as established at the Night Hawk Lake test range is approximately 150 m.

RESULTS

The maps are prepared with a photomosaic base at a scale of 1:20 000 using Ontario Ministry of Natural Resources 1:15 840 and 1:20 000 scale aerial photography. The photos were laid down using a Universal Transverse Mercator projection format constructed from scaling down 1:50 000 topography maps.

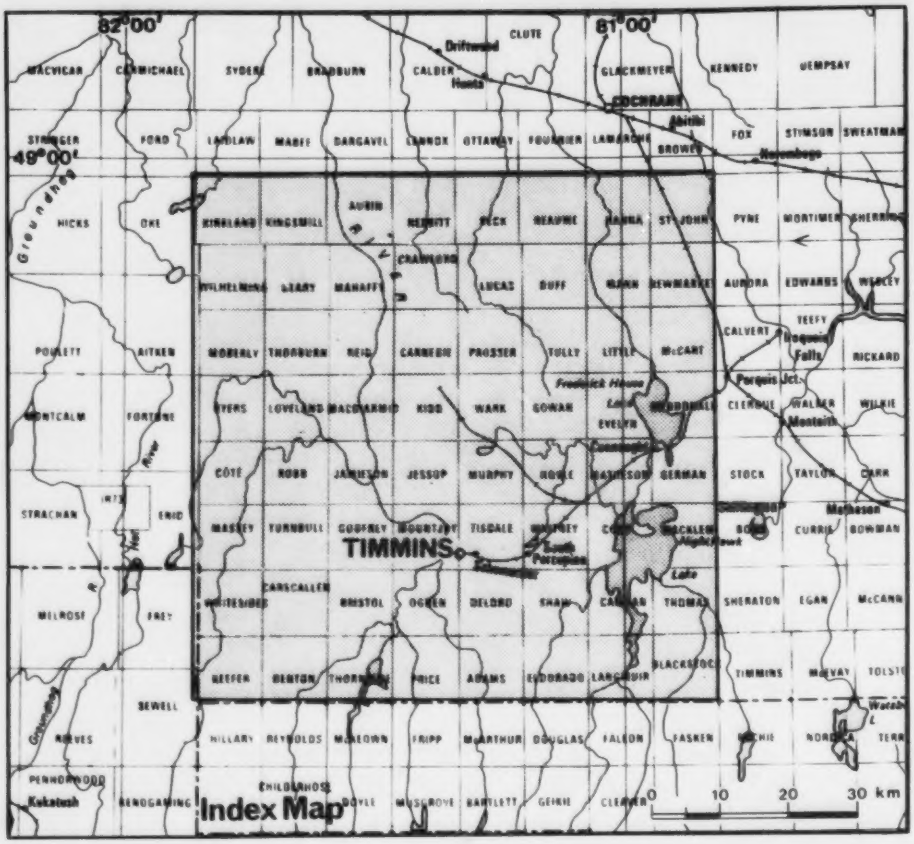
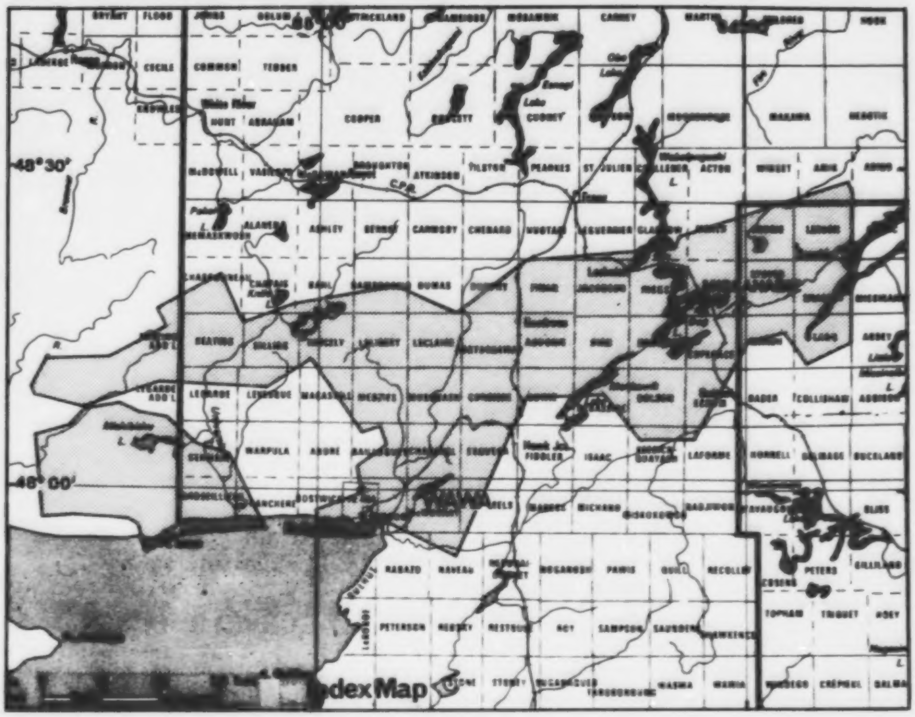

82°00'
81°00'
49°00'
Driftwood
CLUTE
MACVICAR
CARMICHAEL
SYDERE
BRADBURN
CALDER
Hunta
GLACKMEYER
KENNEDY
DEMPSAY
COCHRANE
Abitibi
STRINGER
FORD
LAIDLAW
MABEE
DARGAVEL
LENNOX
OTTAWAY
FOURNIER
LAMARCHE
BROWER
FOX
STIMSON
SWEATMAN
Nooseboga
Groundhog
HICKS
OKE
KINGSMILL
AURIN
BENNETT
BECK
BEAUME
HANNA
ST. JOHN
PYNE
MORTIMER
SHERRING
CRAWFORD
WILHELMINA
LEARY
MAHAFFY
LUCAS
DUFF
MANN
NEWMARKET
AURORA
EDWARDS
WESLEY
TEEFY
POULETT
AITKEN
MOBERLY
THORBURN
REID
CARNEGIE
PROSSER
TULLY
LITTLE
McCART
CALVERT
Iroquois Falls
RICKARD
Frederick House Lake
Porquis Jct.
MONTCALM
FORTUNE
RYERS
LOVELAND
MACDIARMID
KIDD
WARK
GOWAN
EVELYN
CLERGUE
WALKER
Monteith
WILKIE
River
COTE
ROBB
JAMIESON
JESSOP
MURPHY
HOYLE
MATHESON
GERMAN
STOCK
TAYLOR
CLARK
STRACHAN
ENID
MASSEY
TURNBULL
GODFREY
MOUNTJOY
TISDALE
WHITNEY
MACKLEM
BOND
CURRIE
BOWMAN
Matheson
Night Hawk
TIMMINS
South Porcupine
Lake
CARSCALLEN
WHITESIDES
BRISTOL
OGDEN
DELORO
SHAW
CARMAN
THOMAS
SHERATON
EGAN
McCANN
MILROSE
FREY
KEEFER
BENTON
THORNELOE
PRICE
ADAMS
ELDORADO
LANGMUIR
BLACKSTOCK
TIMMINS
McVAY
TOLSTOI
SEWELL
Groundhog
REEVES
HILLARY
REYNOLDS
McKEOWN
FRIPP
McARTHUR
DOUGLAS
FALLON
FASKEN
MACKIE
NORDICA
TERRY
Watabeag L.
PENHORWOOD
CHILDERHOSE
Kukatush
KENOGAMING
Index Map
DOYLE
MUSGROVE
BARTLETT
GEIKIE
CLEAVER
0
10
20
30 km

Figure 78.1C. *Location map for the Timmins AEM survey.*



Location Map D

Figure 78.1D. *Location map for the Wawa AEM survey.*

The flight lines, anomalies, and magnetic contours were superimposed on this base and appropriate legend information was attached. Digital profiles of every flight line were constructed with standard presentation schemes and microfilmed for permanent storage.

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1988b: Airborne Electromagnetic and Total Intensity Magnetic Survey, Wawa Area, Districts of Algoma, Sudbury and Thunder Bay; by Dighem Surveys and Processing Inc., for the Ontario Geological Survey, Maps 81 003 to 81 034, Geophysical/Geochemical Series, scale 1:20 000. Survey and compilation from April 1987 to February 1988.

79. Project Number 87–24. The Detection and Mapping of Basement Conductors Under Areas Covered by Thick Huronian Sedimentary Rocks, District of Timiskaming

James E. Hanneson and Ronald S. Huxter

Geophysicists, Geophysics/Geochemistry Section, Ontario Geological Survey, Toronto.

INTRODUCTION

The electromagnetic (EM) surveying project, initiated in 1986 for tracing conductive strata in Precambrian rocks overlain by thick sedimentary cover, continued in Coleman and Firstbrook townships with the completion of a ground EM survey on about 80 line km of grid cut in 1987 (Figure 79.1). This grid was also expanded (by about ten percent) and refurbished. Late season activities, some of which are presently in progress, include gravity surveying on the 1987 grid, line cutting to extend the 1987 grid eastward another 4 km, EM soundings to study Huronian/Precambrian conductivity contrasts, and additional EM profiling surveys on the grid extensions.

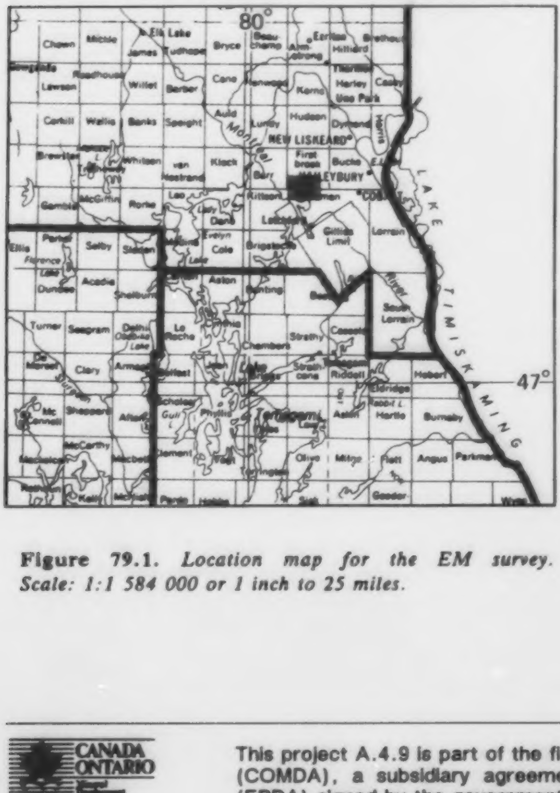
80°
47°
Elk Lake
Chown
Michie
James
Tudhope
Bryce
Beauchamp
Armstrong
Earlton
Brethour
Hilliard
Lawson
Roadhouse
Willet
Barber
Cane
Kerns
Harley
Casey
Uno Park
Cartell
Wallis
Banks
Speight
Auld
Lundy
Hudson
Dymond
Harris
NEW LISKEARD
Montreal
Brewster
Whitson
van Nostrand
Klock
Barr
Firstbrook
Bucke
HAILEYBURY
COBALT
Gamble
McGiffin
Rorke
Lee
Dane
Kittson
Coleman
Lorrain
Gillies Limit
Ellis
Selby
Evelyn
Cole
Brigstocke
Florence Lake
Acadia
Dundee
Shelburn
Aston
Bunting
River
South Lorrain
Turner
Seagram
Delhi
Le Roche
Strathy
Cassels
Chambers
LAKE TIMISKAMING
Clary
Belfast
Strathcona
Riddell
Hobart
Eldridge
Rabbit L.
Mc Connell
Sheppard
Afton
Gull L.
Phyllis
Temagami
Askin
Hartle
Burnaby
McCarthy
Macbeth
Clement
Olive
Angus
Parkman
Kelly
Pardo
Gooder

Figure 79.1. *Location map for the EM survey. Scale: 1:1 584 000 or 1 inch to 25 miles.*

SURVEY EQUIPMENT

The Lamontagne UTEM 3c Transient EM prospecting system continues as the main EM data gathering tool for the project, but limited surveying will also be performed with other transient EM systems (such as the Geonics EM–37 and the Crone PEM) before the completion of the project. Gravity data is presently being collected using Lacoste–Romberg gravimeters with optical leveling equipment.

GROUND SURVEYS, BLOCK A

The 80 km of transect lines, referred to as Block A, 1987 grid, were surveyed using the UTEM system. The three loops used for the UTEM survey are illustrated in Figure 79.2. Also illustrated is the location of Loop 4 which was used for two detailed survey lines near MacLaren Lake; the data of Loop 4 is discussed below. Figure 79.2 also indicates interpreted conductors and their approximate locations based on the UTEM profiling data. The conductors were grossly categorized as late time responses, early time responses, or both late and early time responses. In general, conductors having a late time response have higher conductances normally associated with graphite or massive sulphides, while early time responders tend to be caused by poorly conducting features such as faults, contacts, overburden, or even very low concentrations of graphite or sulphides. It is stressed that the EM anomalies indicated on Figure 79.2 represent preliminary interpretations which may change when quantitative computer modeling is completed for the entire body of data. The authors feel that the interpretation is inadequate for the accurate placement of drillholes. The UTEM profile data from which the preliminary conductor interpretations were made is available as OGS Preliminary Map P.3133. A sample of these profiles is given in Figure 79.3 which indicates a late time response near 13+50S and early time responses near 10+50S and 10+00N.

Significant parts of Block A contain a diabase unit which is commonly associated with economic

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CANADA ONTARIO

This project A.4.9 is part of the five year Canada-Ontario 1985 Mineral Development Agreement (COMDA), a subsidiary agreement to the Economic and Regional Development Agreement (ERDA) signed by the governments of Canada and Ontario.

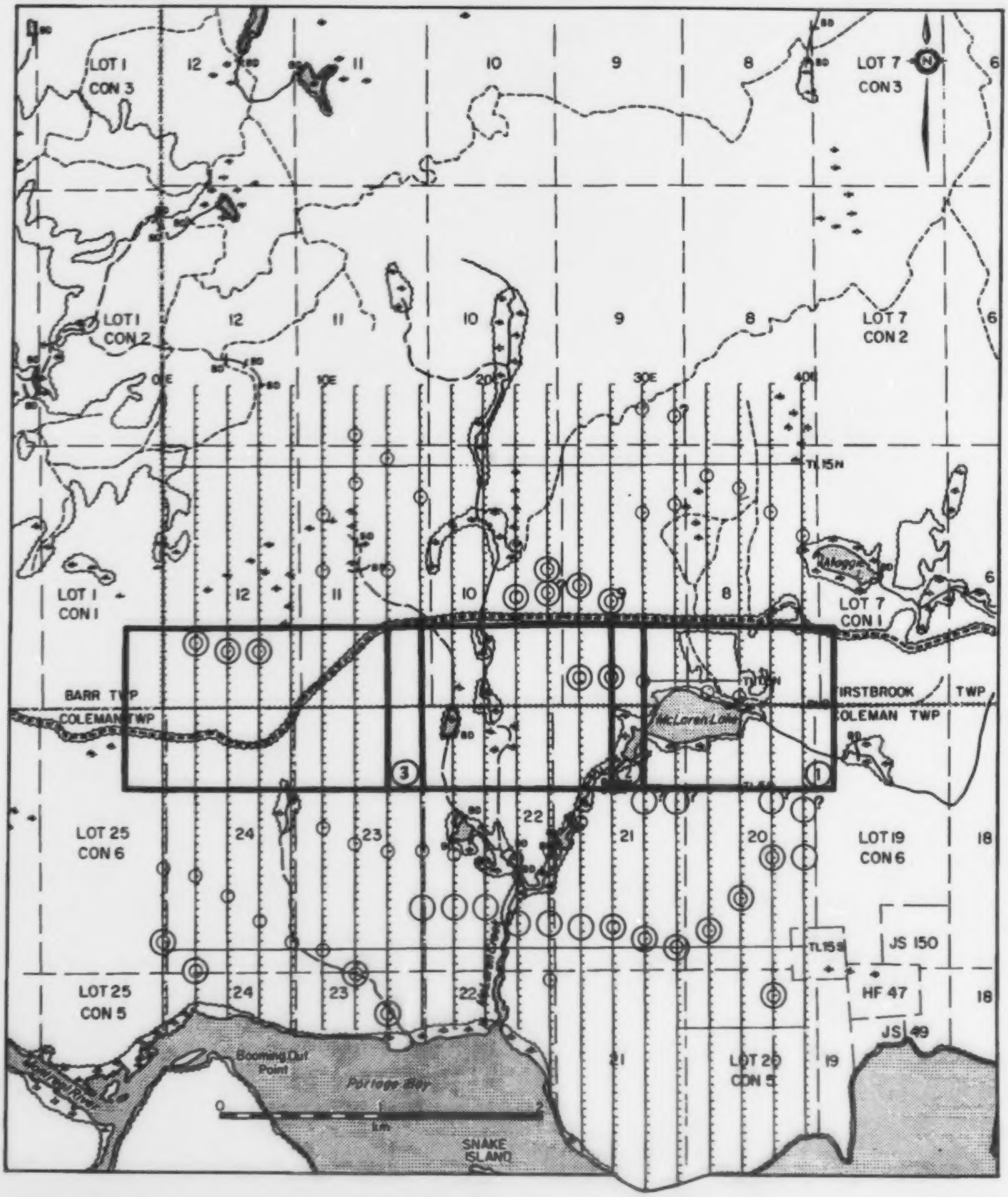
LOT 1
CON 3
12
11
10
9
8
LOT 7
CON 3
6
N
LOT 1
CON 2
LOT 7
CON 2
0E
10E
20E
30E
40E
TL15N
LOT 1
CON 1
LOT 7
CON 1
BARR TWP
COLEMAN TWP
FIRSTBROOK TWP
COLEMAN TWP
McLaren Lake
1
2
3
LOT 25
CON 6
24
23
22
21
20
LOT 19
CON 6
18
TL15S
JS 150
HF 47
JS 49
LOT 25
CON 5
Booming Out Point
Portage Bay
Montreal River
0
1
2
km
SNAKE ISLAND
LOT 20
CON 5
19

Figure 79.2. *Block A grid lines showing UTEM transmitter loops. Late time (open circles) and early time (solid circles) illustrate preliminary interpretation of UTEM anomalies with approximate locations. Interpretation may be subject to change following quantitative computer modeling.*

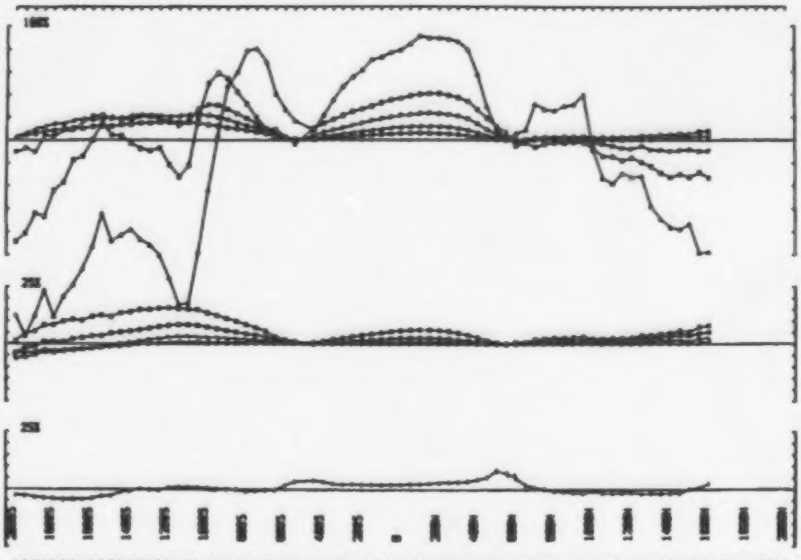

Figure 79.3. *Sample UTEM profile (z-component, line 24E) from which has been interpreted a late time response near 13+50S and early time responses near 10+50S and 10+00N.*

mineralization in the Cobalt mining camp. This unit is more dense than typical units in either the Huronian or Precambrian rocks, and a gravity survey is presently in progress to assist in mapping the extensiveness of the diabase. The survey is being performed by Geoterrex Limited of Ottawa, under contract to the Ontario Geological Survey.

LINE CUTTING, BLOCKS B AND C

The conductors detected on Block A suggested that a reasonable return of geological information could be expected from an extension of the survey. After securing consents from the holders of surface rights, plans for the cutting of Blocks B and C were finalized and cutting is presently in progress under contract, by Lashex Ltd. of Callander, Ontario. Blocks B and C, along with Block A are illustrated in Figure 79.4.

EXAMPLES OF QUANTITATIVE MODELING OF FIELD DATA

Lines 28E and 30E between 500N and 500S were surveyed using Loop 4 to better define a conductor near MacLaren Lake. The survey data for Line 28E is given in Figure 79.5 for both x– and z–components. Forward modeling using a plate–in–free–space model (Hanneson and Huxter 1986) accurately simulates the late time responses for the MacLaren Lake conductor which is shown to be near vertical and of very limited depth extent.

The late time responder near the southern tie line between lines 16E and 34E is poorly defined by the profiles, and the southward extension of lines 22E to 40E was undertaken to provide additional coverage and a second transmitter loop location. Preliminary free space model results suggest that the depth of this feature may be in the 500 m range but additional data is required to confirm or revise this figure.

Other late time responses were detected but not with sufficient continuity to permit quantitative interpretations. Several early time responses were detected but have not been interpreted quantitatively; they are probably the result of galvanic processes and require plate–in–host models for adequate simulation.

CONCLUSIONS

Following the feasibility studies completed early in 1987, the systematic collection of UTEM data late in the year revealed several EM responders in what are probably Archean formations. The survey area has been extended, mainly to the east, and additional EM surveying is expected to reveal more conductors and more information on the Archean basement.

FUTURE WORK

The gravity work in progress on Block A will be extended to Blocks B and C, as will the UTEM profile coverage. Ground magnetics and VLF–EM surveys are also planned for the 1988 and 1989 field seasons. In the immediate future, sounding techniques will be attempted on Block A in cooperation with Lamontagne Geophysics Limited for the purpose of

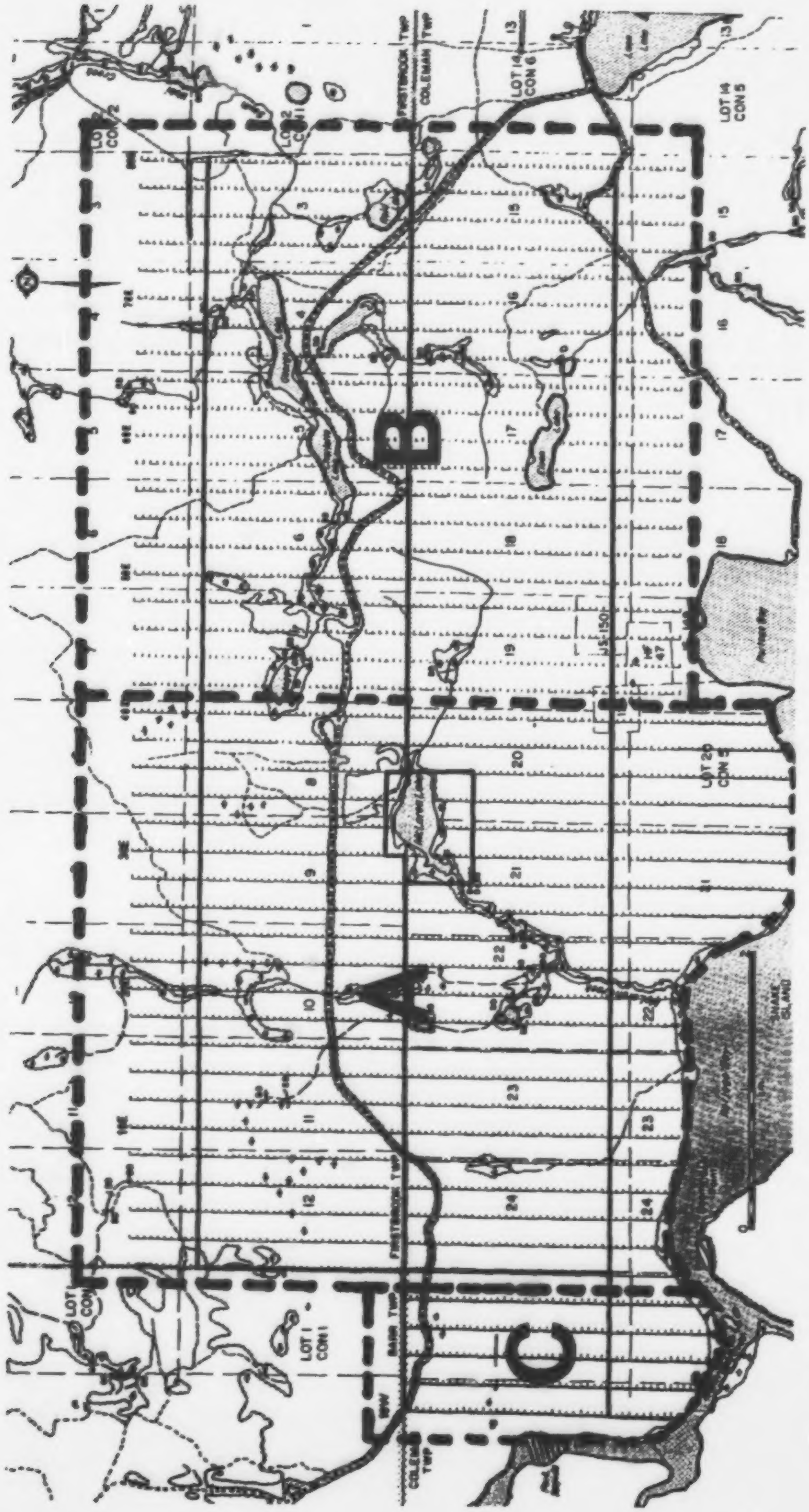
A
B
C
FIRSTBROOK TWP
COLEMAN TWP
BARR TWP
LOT 14
CON 6
LOT 14
CON 5
LOT 20
CON 5
LOT 1
CON 1
SNAKE ISLAND
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Figure 79.4. *Grid Blocks A, B, and C.*

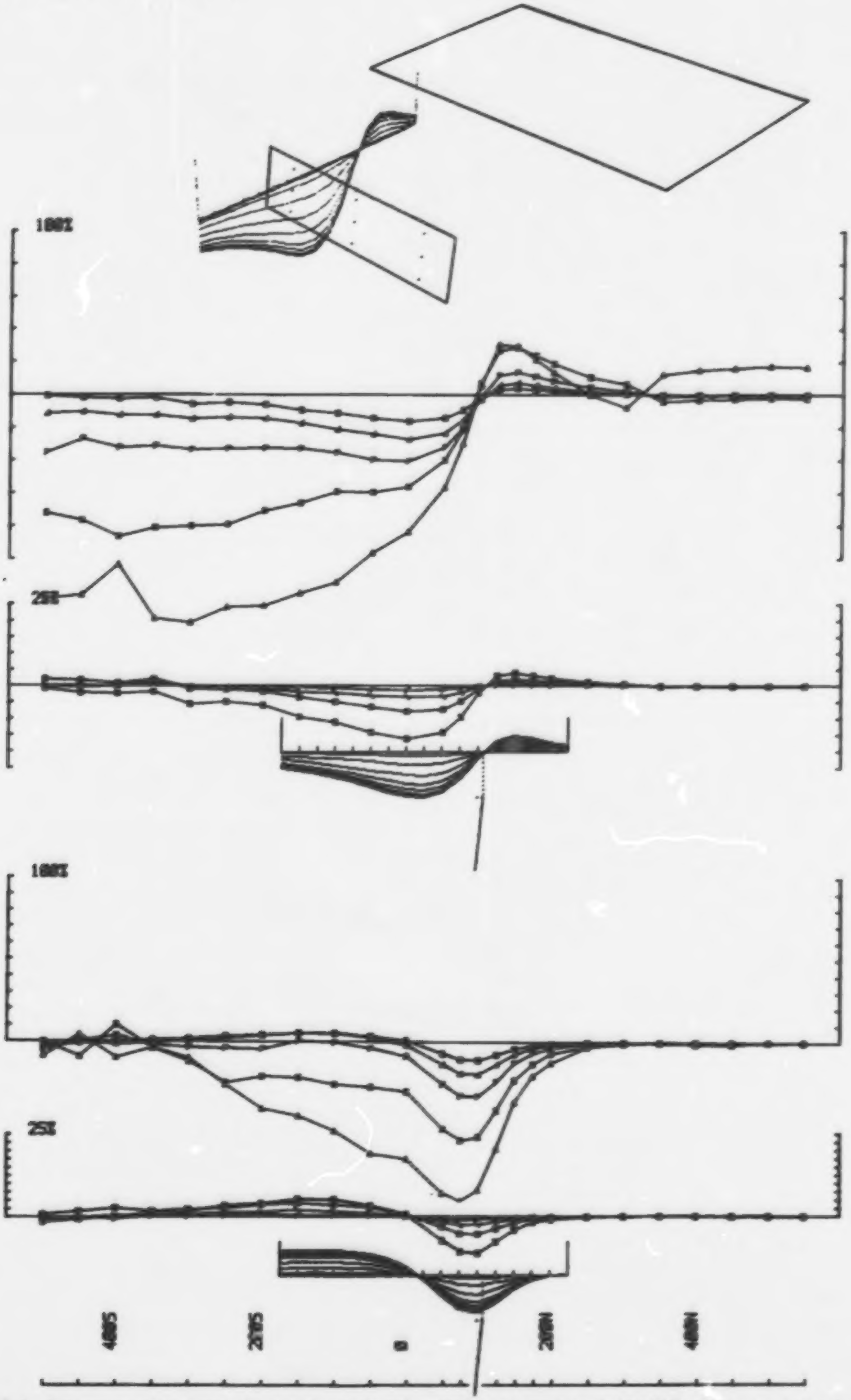

Figure 79.5. *Perspective view (top) showing Loop 4 and a modeled segment of line 28E. Measurements of the vertical component (middle) and horizontal component (lower) are presented with plate-in-free-space responses (insets). The wide-band observed response resembles the computed plate-in-host responses (see Hanneson and Huxter 1987) but a plate-in-free-space model is adequate for late times. The anomaly must be a small plate-like body of limited depth extent (120 m) at about 75 m depth and having a high conductance (140 siemens).*

determining conductivities in the Huronian and Archean rocks and, if different, the depth to the unconformity in areas remote from basement conductors. Modeling studies will continue with the implementation of plate–in–host EM algorithms for the purpose of simulating all EM transient channels rather than just late time channels as is presently possible with free space models.

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80. Project Number 88–38. Lithoprobe Gravity Profiles—Chapleau, Kapuskasing and Kirkland Lake Areas

R.B. Barlow[1] and D.R. Wadge[2]

[1]Chief, Geophysics/Geochemistry Section, Ontario Geological Survey, Toronto.

[2]Geophysical Assistant, Geophysics/Geochemistry Section, Ontario Geological Survey, Toronto.

INTRODUCTION

Gravity profiling was carried out during the fall (1987) and winter (1988) months by staff of the Geophysics/Geochemistry Section of the Ontario Geological Survey, along planned seismic reflection transects which were completed as part of two major Lithoprobe projects. Lithoprobe is an umbrella program in which multidisciplinary earth science projects are proposed, approved, and carried out by geoscience agencies and university departments in order to explore crustal features across Canada, thereby advancing our understanding of geological processes historically active within the earth's crust.

This program is largely funded by the Government of Canada (Energy, Mines and Resources), however, the Ontario Geological Survey and the Ministére de l'Energie et des Ressources, Quebec have sponsored seismic reflection transects in key areas of the Abitibi Belt. As well, the Ontario Geological Survey funded and carried out the gravity profiling of most seismic transects which were completed in Ontario during the same period. The gravity measurements and subsequent results were obtained cost effectively because of the existence of first order leveling and positioning data obtained as part of the seismic work.

LOCATION

The Chapleau–Foleyet survey area is bounded by Latitudes 47°30′N and 48°30′N and Longitudes 82°00′W and 84°00′W, covering the southern portion of the Kapuskasing Structural Zone. The Kapuskasing survey area is bounded by Latitudes 49°00′N and 49°30′N and Longitudes 82°00′W and 82°30′W. The Kirkland Lake survey area is bounded by Latitudes 48°00′N and 48°45′N and Longitudes 79°30′W and 80°00′W, centrally located in the Abitibi Greenstone Belt and crossed by the Destor–Porcupine and Kirkland Lake–Larder Lake Fault Zones on the north and south respectively.

The location of the areas is shown in Figure 80.1.

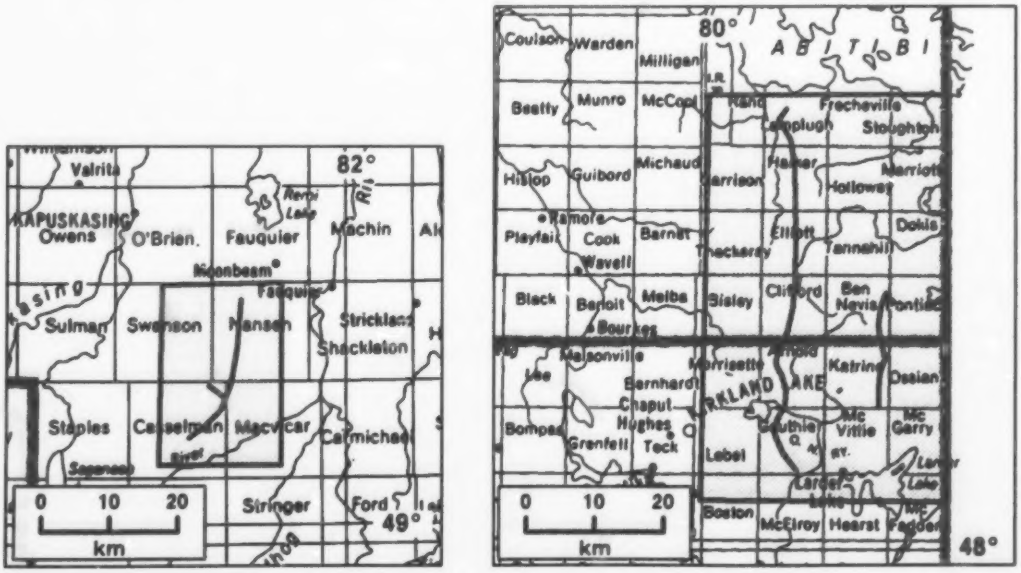

Valrita
KAPUSKASING
Owens
O'Brien
Fauquier
Moonbeam
Machin
82°
Sulman
Swanson
Hanson
Fauquier
Strickland
Shackleton
Staples
Casselman
Macvicar
Carmichael
Stringer
Ford
49°
0 10 20
km
80°
ABITIBI
Coulson
Warden
Milligan
Beatty
Munro
McCool
Rand
Frecheville
Lamplugh
Stoughton
Hislop
Guibord
Michaud
Garrison
Harker
Holloway
Marriott
Ramore
Playfair
Cook
Barnet
Thackeray
Elliott
Tannahill
Dokis
Wavell
Black
Benoit
Melba
Bisley
Clifford
Ben Nevis
Pontiac
Bourkes
Maisonville
Morrisette
Lee
Bernhardt
Katrine
Ossian
KIRKLAND LAKE
Bompas
Chaput Hughes
Grenfell
Teck
Lebel
Gauthier
Mc Vittie
Mc Garry
Larder Lake
Boston
McElroy
Hearst
McFadden
48°
0 10 20
km

Figure 80.1a. *Location map for the Kapuskasing and Kirkland Lake areas.*

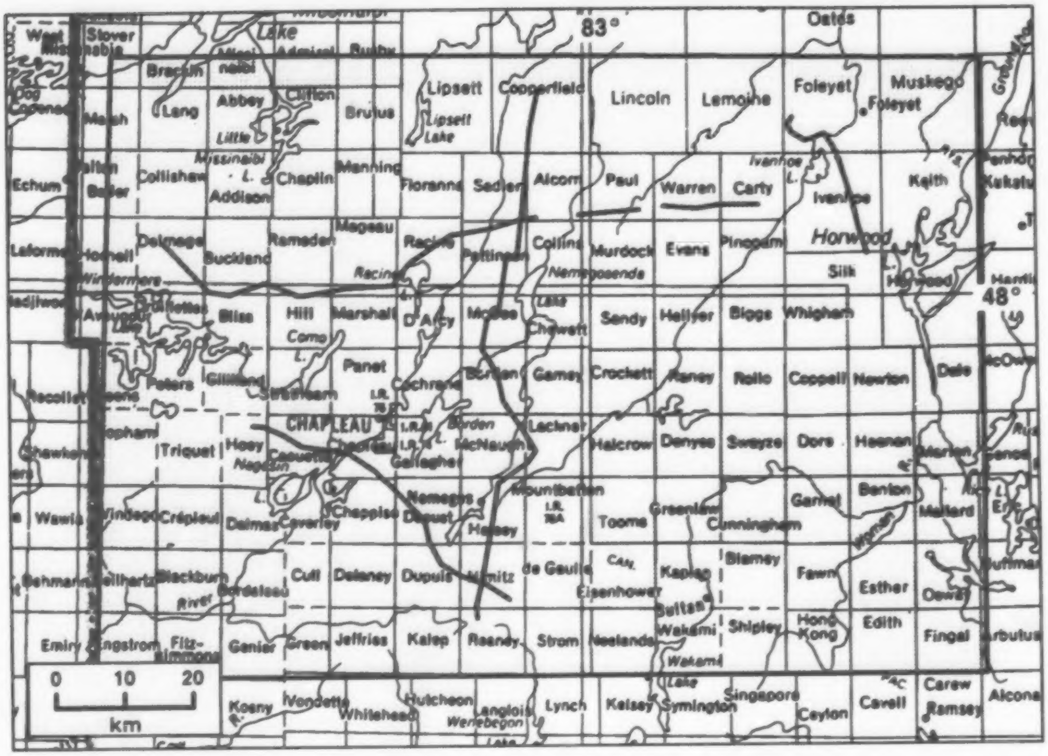


Figure 80.1b. *Location map for the Chapleau area.*

GRAVITY SURVEY

During September and October of 1987, and January of 1988, over 1850 gravity stations were established on seismic traverse lines located along highways, and lumber and forest access roads within the three areas.

Lacoste–Romberg gravimeter G–294 was used for the survey with a station spacing of 200 m along the lines. The gravity observations were tied to local control stations that form part of the National Gravity Network.

Vertical control (or elevation) of the gravity stations was provided by taking readings at surveyed seismic vibe points. Surveying of the lines was carried out by Eagle Surveys Ltd. of Calgary. Horizontal control of the station locations was obtained from Eagle Surveys as U.T.M. northings and eastings.

The gravity survey was carried out to the specifications and procedures of the Gravity Division of the Geological Survey of Canada, where the data was processed. Profiles and digital data resulting from the field work will be released during the winter of 1989.

81. Project Number 87–29. Reconnaissance Till Sampling Program, Matheson–Lake Abitibi Area, District of Cochrane

K.G. Steele

Geologist, Engineering and Terrain Geology Section, Ontario Geological Survey, Toronto.

INTRODUCTION

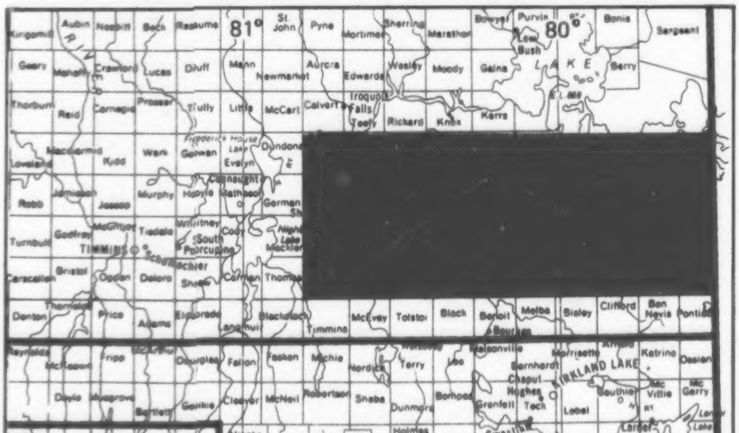
A reconnaissance scale overburden sampling program in the Black River–Matheson (BRIM) area began in 1984 and is to be completed in 1989 (Figure 81.1). The program is a combined effort of the Geophysics/Geochemistry and the Engineering and Terrain Geology sections of the Ontario Geological Survey. The BRIM area has extensive and thick drift cover; less than 5 percent of the area is outcrop. The regional Quaternary (glacial) stratigraphy and a till geochemistry data base are being established from the results of the till sampling program. The data and interpretations produced by the program are of practical importance for exploration.

TILL SAMPLING

Three till sampling methods were used in the program: sonic drilling, backhoe trenching, and hand–dug pits. This combination of methods was cost effective in providing samples from surface to bedrock in a study area with variable drift thickness. Using several sampling methods also allowed an even distribution of sample sites over the area.

In areas of shallow drift, or when till occurs at surface, backhoe trenching was used to search for and sample till. When these areas were only accessible by boat or floatplane, pits were dug by hand.

In areas of thick drift, a sonic drill was used because it furnishes a continuous, relatively undis-



81°
80°
48°
St. John
Pyne
Mortimer
Aubin
Nesbitt
Beck
Reaume
Geary
Crawford
Lucas
Dluff
Mann
Newmarket
Aurora
Edwards
Wesley
Moody
Gains
Bonis
Sargeant
Berry
Purvis
Low Bush
LAKE
Thorburn
Reid
Carnegie
Prosser
Tully
Little
McCart
Calvert
Iroquois Falls
Teefy
Rickard
Knox
Kerrs
Loveland
Kidd
Wark
Godwin
Frederick House Lake
Evelyn
Dundonald
Robb
Jamieson
Jessop
Murphy
Hoyle
Matheson
German
Turnbull
Godfrey
Tisdale
Whitney
South Porcupine
Cody
Night Hawk Lake
Mackler
TIMMINS
Schumacher
Carscallen
Bristol
Ogden
Deloro
Shaw
Carman
Thomas
Denton
Price
Adams
Eldorado
Langmuir
Blackstock
Timmins
McEvay
Tolstoi
Black
Benoit
Melba
Bisley
Clifford
Ben Nevis
Pontiac
Fripp
Douglas
Fallon
Fasken
Michie
Nordica
Terry
Lee
Morrisette
Bernhardt
Katrine
Ossian
KIRKLAND LAKE
Chaput Hughes
Teck
Lebel
Gauthier
McVittie
McGarry
Dunmore
Bompas
Grenfell
Sheba
Robertson
McNeil
Cleaver
Geikie
Bartlett
McBride
English
Zavitz
Hincks
Argyle
Baden
Alma
Holmes
Burt
Eby
Swastika
Otto
Boston
McElroy
Hearst
Larder Lake
Robin
Gouin
Semple
Montrose
Bannockburn
Powell
Cairo
Flavelle
Gross
Blain
Marquis
Pacaud
Catherine
Skead
Rattray
Doon
Matachewan
Kimberley
Willison
Davidson
Sharpe
Severn
Chamberlain
Marter
Bayly
Mulligan
Rankin
Shillington
Farr
Smyth
Truax
Dack
Eventure
Ingram
Evanturel
Englehart
Burrows
Kamo
Nesbitt
TIMISKAMING
Elk Lake
Earlton
Brethour

Figure 81.1. *Location map for the reconnaissance till sampling program, Matheson–Lake Abitibi area, District of Cochrane. Scale: 1:1 584 000 or 1 inch to 25 miles.*

This project is part of Operation Black River–Matheson (BRIM) which is funded by the Ontario Ministry of Northern Development and Mines.

turbed, 88 mm diameter core from all formations including bedrock. The core provides a detailed stratigraphic record for the interpretation of depositional environments, and large, complete samples for geochemical analyses. Drilling methodology and operations are described in Baker *et al.* (1985) and Averill *et al.* (1986).

Till samples collected by drill, backhoe, and hand were processed in a similar manner. Processing steps and analytical procedures used were outlined in Baker *et al.* (1985) and Bloom (1987). By combining geochemical, mineralogical, texture, carbonate, and clast data, units can often be separated within a drillhole or correlated between sampling sites.

PREVIOUS SAMPLING PROGRAMS

In the period from July 1984 to June 1987, three sonic drilling and four near surface till sampling (backhoe trenching and hand–dug pits) programs were carried out in the BRIM area. Prior to the 1988 field work, 282 near surface till samples had been collected and 173 sonic drillholes had been completed (Figure 81.2). From the drill core 810 till, 365 glaciofluvial sand, and 170 bedrock samples were collected.

Core for holes drilled in the Larder Lake Mining Division (all of the study area except for the four westernmost townships) is stored at the Kirkland Lake Drill Core Library. Core for holes drilled in the Porcupine Mining Division (holes drilled in Sheraton, Stock, Bond, and Clergue townships) is stored at the Timmins Drill Core Library. All bedrock and till core from the 1984, 1985, and 1987 sonic drill programs is available for public inspection.

SAMPLING IN 1988

During February and March 1988, a 52–hole sonic drilling program was completed in the eastern part of the BRIM area (Figure 81.2). Holes were sited along existing roads and trails cleared for this program, newly constructed winter roads, and on the ice of Lake Abitibi. The program included drilling at 40 sites which are inaccessible during summer months and detailed stratigraphic drilling at 12 sites located near three previous drillholes. This program completes overburden sampling in the BRIM area.

The 1988 drill program was completed over a 35–day period, using two 12–hour shifts per day. A tracked vehicle (Go–Trac) mounted drill system was utilized for all drillholes except those on Lake Abitibi. The weight of this system necessitated a change to a skid mounted drill system for holes on the lake ice. In the 52–hole program, 1698 m of drift and 103 m of bedrock were drilled. Hole 88–19 on Lake Abitibi was abandoned before reaching bedrock because the drill shifted as water flowed onto the ice. The average overburden thickness (excluding four holes drilled in the northwestern part of the BRIM area) was 30.5 m. This compares with average overburden thicknesses of 35 m, 42 m, and 36 m in the 1984, 1985, and 1987 drill programs, respectively. The reduction in average overburden thickness for the 1988 program indicates that, in general, drift is thinner in the eastern part of the BRIM area.

In selection of 1988 drill sites, the following criteria were deemed most important: an even distribution of data points over the study area; locating holes over east–west oriented bedrock valleys as interpreted from airborne electromagnetic data; avoidance of esker sediments; and siting holes in areas of complex or unknown bedrock geology. Sites drilled in 1988 were concentrated in Tannahill, Elliott, Stoughton, and Holloway townships. Holes were also drilled in Dokis, Garrison, Harker, Marriott, Frecheville, and Rand townships, Abitibi Indian Reserve 70, and on Lake Abitibi. For stratigraphic information, fences of holes were drilled in Walker, Lamplugh, and Harker townships about holes 87–21, 85–42, and 85–39, respectively.

From the 1988 drill core 269 till, 42 glaciofluvial sand or sand and/or till, and 50 bedrock samples were collected. Analytical and stratigraphic results of the 1988 drilling program are expected to be released in data sheet and floppy diskette formats during the spring of 1989. Preliminary information on the number and distribution of visible gold grains in the sonic drill core samples is available in Steele (1988).

QUATERNARY HISTORY/STRATIGRAPHY

SURFACE MAPPING AND RECONNAISSANCE DRILLING

The most recent glacial advance across the BRIM area was toward 170° azimuth and deposited the Matheson till (informal name). During the latter stages of ice cover, esker systems, which trend parallel to the ice flow direction, were developed. As the ice front receded northward approximately 10 000 years before present, it was fronted by glacial lakes Barlow and Ojibway. The existence of these bodies of water resulted in the deposition of thick and extensive glaciolacustrine clay deposits which mask most of the bedrock and lap onto the esker systems.

Evidence of an earlier ice movement is exposed at the Maude Lake pit (northwest Beatty Township), where 170° azimuth striae cross–cut 240° azimuth striae. Southwest–trending striae in the BRIM area have also been reported by Richard and McClenaghan (1985) and Veillette (1986).

Sonic drilling in the BRIM area has indicated the presence of two glacial packages under the Matheson till. The regional composite Quaternary (glacial) stratigraphy can be summarized, from top (youngest) to bottom, as follows:

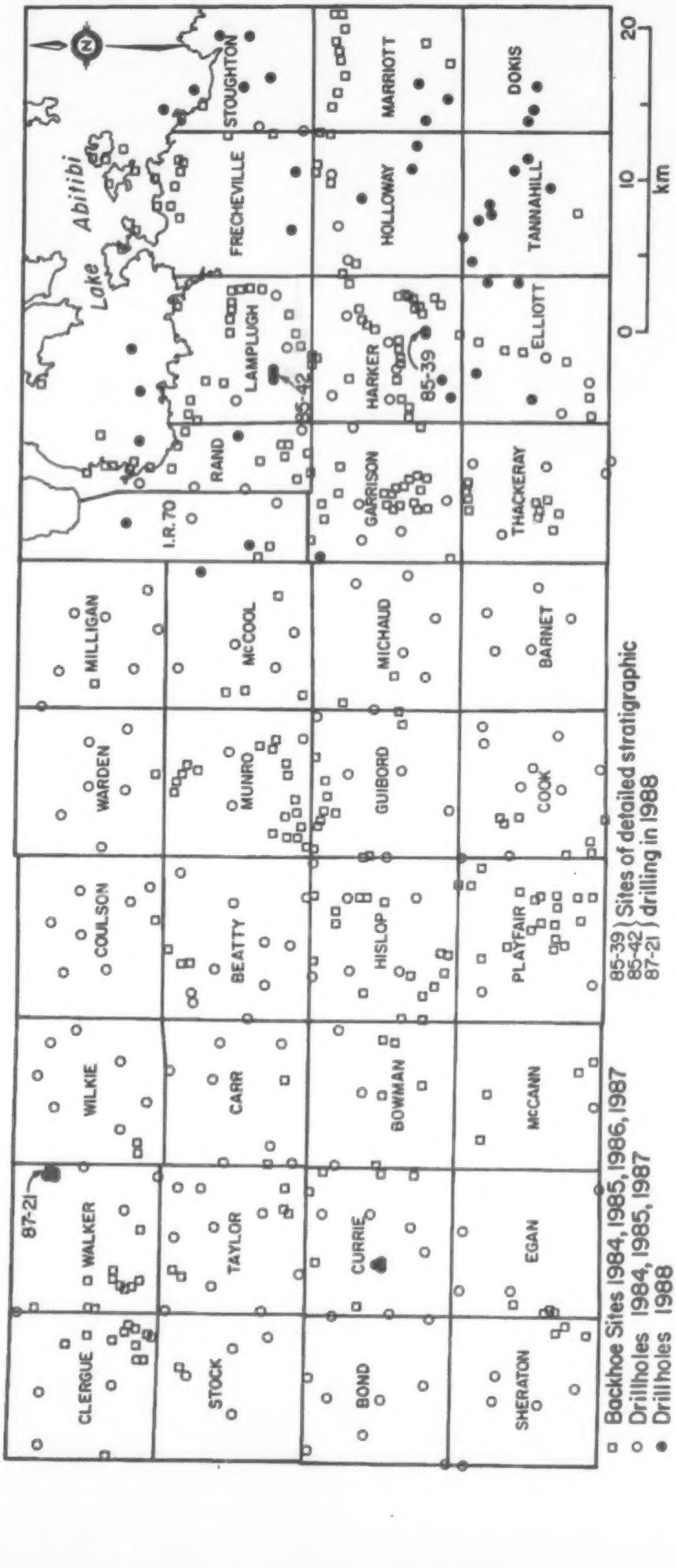

Lake Abitibi
N
STOUGHTON
MARRIOTT
DOKIS
FRECHEVILLE
HOLLOWAY
TANNAHILL
LAMPLUGH
HARKER
ELLIOTT
85-42
85-39
RAND
GARRISON
THACKERAY
I.R. 70
MILLIGAN
McCOOL
MICHAUD
BARNET
WARDEN
MUNRO
GUIBORD
COOK
COULSON
BEATTY
HISLOP
PLAYFAIR
WILKIE
CARR
BOWMAN
McCANN
87-21
WALKER
TAYLOR
CURRIE
EGAN
CLERGUE
STOCK
BOND
SHERATON
0
10
20
km
□ Backhoe Sites 1984, 1985, 1986, 1987
○ Drillholes 1984, 1985, 1987
● Drillholes 1988
85-39
85-42
87-21
Sites of detailed stratigraphic drilling in 1988

Figure 81.2. *BRIM overburden sample sites.*

1. Matheson package – Glaciolacustrine sediments (largely varved clay and silt) overlying till. Glaciofluvial sand occasionally occurs between these units. The glaciolacustrine sediments deposited in proglacial lakes Barlow and Ojibway can be up to 75 m thick. Till thicknesses are usually less than 10 m; however, up to 30 m of Matheson till has been encountered in the BRIM area. Deposits of this package are associated with ice which advanced toward 170° azimuth.
2. Middle package – This package is restricted in areal extent and was encountered in approximately 30 percent of drillholes and in sections at the Maude Lake pit (northwest Beatty Township). The stratigraphy of the package is glaciolacustrine sediments overlying glaciofluvial sand which in turn overlies till. The most common sediment sequence encountered is varved clay and silt overlying sandy silt to silty sand till. At some drill sites and the Maude Lake pit, till was the only sediment of this package present. As determined from striae and pebble fabric data, sediments of this package are associated with ice which advanced toward 240° azimuth.
3. Lowest package – This package is very restricted in areal extent and has not been seen in section. The largest known subcrop of the Lowest package is in central Currie Township. The usual stratigraphy of this package is varved clay and silt overlying till. The varved sediments are not always present. There is evidence in the Timmins area that the Lowest glacial package is associated with ice which advanced toward 150° azimuth (Alcock, in preparation).

DETAILED STRATIGRAPHIC STUDIES

In 1988, three fences of holes were drilled for stratigraphic studies (Figure 81.2). In all cases, holes were drilled 100 m apart or away from previous sonic drillholes. Geochemical data is not presently available for the 1988 drill program. The following interpretations are based on unit and parameter changes observed during logging of 1988 drill core, and drill core descriptions and analytical results for the 1985 and 1987 drillholes.

Two of the three fences encountered two glacial packages. The fence in Lamplugh Township, at hole 85–42 (Figure 81.2), has a consistent stratigraphy over its 600 m length. At this fence, the Matheson package overlies till from an older (probably Middle) package which in turn overlies bedrock. The stratigraphy of the Matheson package is varved clay and silt overlying sand (and occasionally gravel) which overlies a grey-coloured till. In the seven holes, the thickness of Matheson till ranges between 10 m and 37 m. The sharp break between the Matheson till and the underlying till is marked by changes in matrix colour and clast lithologies. The older till has a distinct green colour and abundant Paleozoic carbonate clasts. Preliminary results indicate that this till has higher concentrations of gold, particularly within 3 m above bedrock (Steele 1988). The older till is up to 17 m thick and, in general, thins toward the west.

The fence in Harker Township, at hole 85–39 (Figure 81.2), is sited on an ice-contact delta. Two of the three holes encountered two glacial packages. At these holes, the Matheson package consists of deltaic sand overlying interbedded till and sand. The top of the older package is marked by varved clay and silt. Beneath these glaciolacustrine sediments are till, sand and gravel units to bedrock. One hole in this fence may contain only the Matheson package or Matheson and an older package. If two packages are present, the older package consists only of till. The description and stratigraphy of the drill core did not provide adequate information to determine the number of glacial packages. Future analytical results may indicate the presence of one or two packages.

Units encountered and descriptions made during logging of hole 87–21, Walker Township (Figures 81.2 and 81.3), indicated the presence of three glacial packages. A 14.3 m thick unit of glaciolacustrine sand and clay at the 29.0 m depth marked the top of the Middle glacial package. An oxidized surface on a till unit at the 51.1 m depth and shifts in chemical results between 51.1 m and 60.4 m confirmed the presence of the Lowest glacial package.

In 1988, holes were drilled 100 m west (88–49), north (88–50), south (88–51), and east (88–52) of hole 87–21 in an attempt to trace the three packages (Figure 81.3). All holes were sited on a flat, level glaciolacustrine clay plain.

Both holes 88–49 and 88–50 encountered bedrock at a much shallower depth than the original hole. Only two glacial packages are present at these two holes. At hole 88–50, the shallowest hole, the Middle glacial package is represented by glaciolacustrine sediments only. At hole 88–49, the Middle package consists of varved clay and silt overlying till on bedrock.

Holes 88–51 and 88–52 were approximately the same depth as the original hole. The stratigraphy at these two holes clearly represents three glacial packages. At the top of each package is a significant thicknesses of glaciolacustrine clay, silt and/or sand. The three glacial packages can easily be correlated between holes 87–21, 88–51, and 88–52.

The fence of holes about hole 87–21 illustrates the influence of the bedrock surface on the occurrence and preservation of sediments beneath the Matheson till. The bedrock surface rises to the north and west and lowers to the east of hole 87–21. Holes 87–21, 88–51, and 88–52 are in the lee of a bedrock high for the earliest, 150° azimuth ice advance. Till of the Lowest package may have only been de-

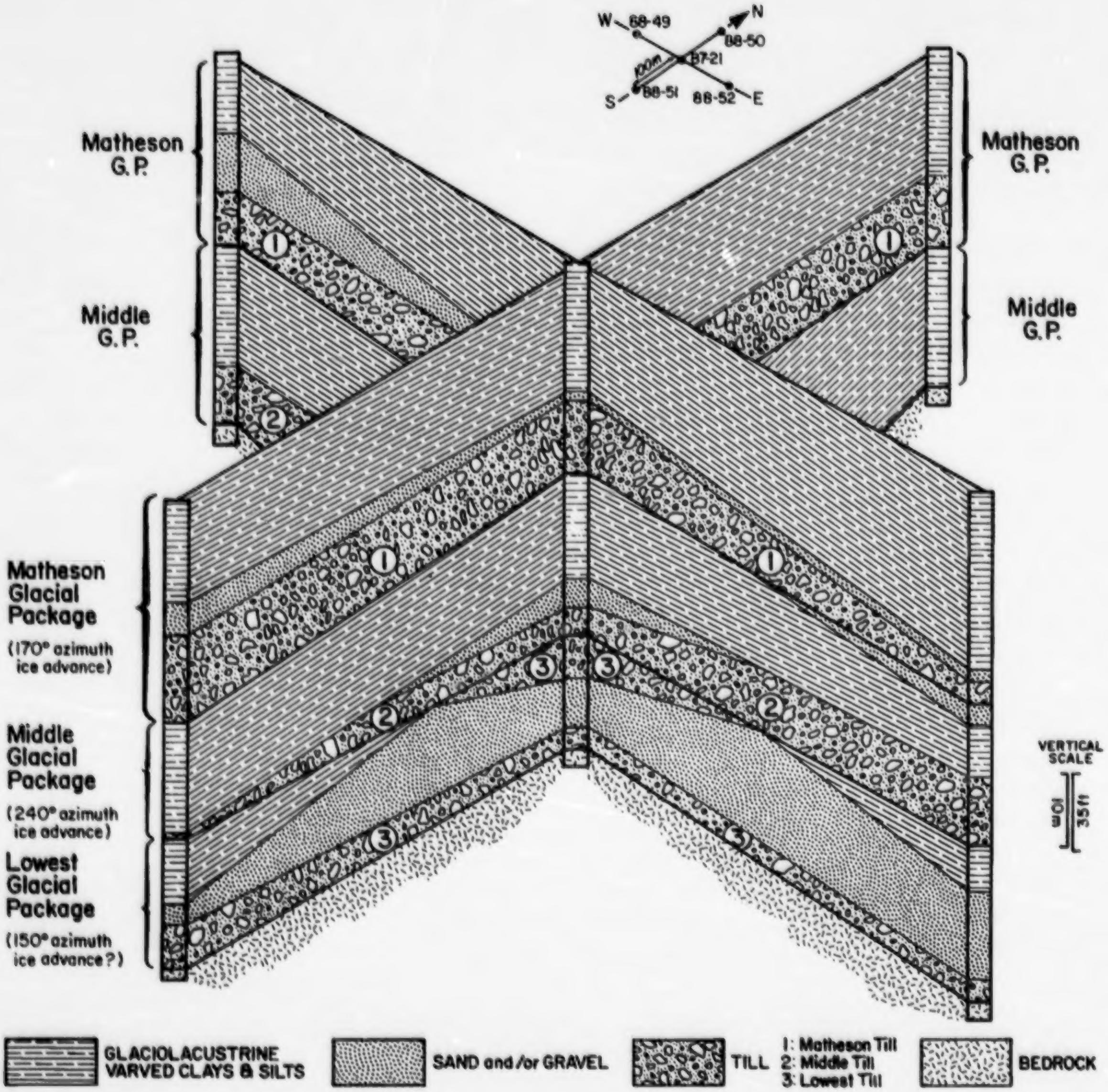

W
88-49
N
88-50
87-21
100m
S
88-51
88-52
E
Matheson G.P.
Middle G.P.
Matheson G.P.
Middle G.P.
1
2
1
1
1
2
3
3
2
3
3
Matheson Glacial Package
(170° azimuth ice advance)
Middle Glacial Package
(240° azimuth ice advance)
Lowest Glacial Package
(150° azimuth ice advance?)
VERTICAL SCALE
10m
35ft
GLACIOLACUSTRINE VARVED CLAYS & SILTS
SAND and/or GRAVEL
TILL
1: Matheson Till
2: Middle Till
3: Lowest Till
BEDROCK

Figure 81.3. *Detailed Quaternary stratigraphy at hole 87-21, northeastern Walker Township.*

posited in the lee–side cavity, with glaciolacustrine sediments filling up the remainder of the bedrock depression. During the next glacial event, ice advancing toward 240° azimuth rode up over the bedrock high eroding any glaciolacustrine sediments that had been deposited on it. However, sediments along the shoulder of the bedrock high (at holes 87–21, 88–51, and 88–52) were protected from erosion. During this period of glacial activity, the Middle till was deposited (except at hole 88–50). This was followed by the deposition of a thick sequence of glaciolacustrine sediments, leaving a relatively level surface. The Matheson glacial event resulted in a relatively uniform sediment sequence being deposited over the area. This sequence consists of till, with sand horizons, overlain by clay, silt and sand deposited in proglacial lakes Barlow and Ojibway.

PUBLICATIONS

Maps, data sheets, and reports containing information and interpretations on the BRIM till sampling program that were published as of December 1987, are listed in Steele and Baker (1987). The following maps and data sheets were published between December 1987 and December 1988:

Data Sheets

1987 Sonic drillholes; Ontario Geological Survey, Maps 81099 to 81135

1986 and 1987 Surface till samples; Ontario Geological Survey, Maps 81136 and 81137

Gold Grains Map

1988 Drilling; Ontario Geological Survey, Map P.3130

It is expected that data sheets for the 1988 drilling and bedrock maps for the 1987 and 1988 drilling will be published in the spring of 1989. Review of the data by the BRIM program has resulted in an overview of the regional glacial stratigraphy by Steele *et al.* (in press) and a discussion of the occurrence of gold in till in the study area by Bloom and Steele (in press).

Data for overburden samples collected from the 1984 through 1987 BRIM sonic drilling and backhoe trenching programs, is available as a series of ASCII files on five-and-a-quarter inch PC-DOS/MS-DOS-compatible floppy diskettes. Sample locations and material types, mineralogical, geochemical, and lithological analyses are provided. Documentation included describes individual file contents and formats. Requests for data must be accompanied by eight (8) formatted double-sided, double-density five-and-a-quarter inch floppy diskettes. There is no charge to copy the data onto these diskettes. Requests should be forwarded to the author (Telephone 416-965-1183).

Data for overburden samples from the 1988 BRIM sonic drilling program will be available on diskettes when the data sheets for these drillholes are published in the spring of 1989.

ACKNOWLEDGMENTS

Field work described herein was completed with the competent assistance of B.R. Hart, S.E. Sparks, C.L. Horvath, R.S. Ramshaw, and B. Antal. The Ontario Geological Survey wishes to thank the individuals and companies who were party to discussions, who provided access and allowed construction of winter roads and drilling on their properties.

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82. Project Number 87–25. A Regional Geochemical Survey of Part of the Batchawana Greenstone Belt, District of Algoma

John A.C. Fortescue

Research Geochemist, Geophysics/Geochemistry Section, Ontario Geological Survey, Toronto.

INTRODUCTION

During 1987, the sampling for the first part of a three year regional geochemical survey of the Batchawana Greenstone Belt was completed in the Wart Lake area (Fortescue and Stahl 1987a). During July and August 1988, the remaining lake sediment and water sampling required for the project was completed (*see* Figure 82.1). In 1988, a total of 947 lake sediment core and water samples were collected from an area of 2475 km². When these are combined with 531 samples collected from the area previously, this makes a grand total of 1478 sample sites for the entire area at an average density of one per 1.67 km². The extent of the regional geochemical survey in relation to the entire Batchawana Synoptic Map area (as described by Grunsky 1982) is indicated on Figure 82.2. An example of the sample density and distribution in the regional geochemical survey is provided in a square inset to Figure 82.2, where each dot indicates a sample site location.

The purpose of the regional geochemical survey is to provide geochemical information of direct importance to exploration in the Batchawana Greenstone Belt. This is done either by confirming, and possibly extending, areas of known mineralization, or by indicating new areas within which mineralization may occur. The COMDA regional geochemical mapping project covers the central and western part of the Batchawana Greenstone Belt and includes

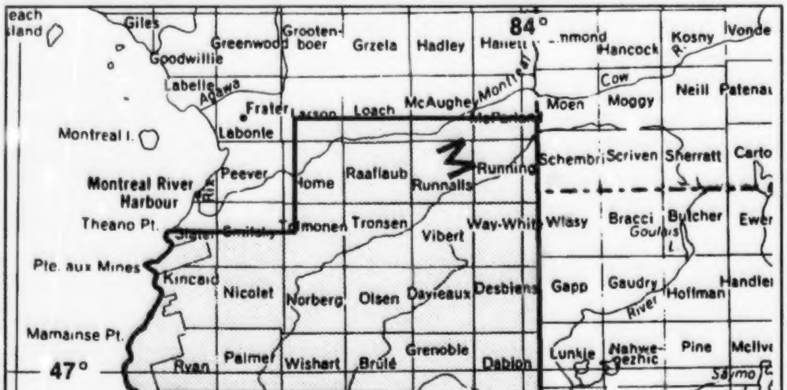
84°
47°
Giles
Greenwood
Grooten-boer
Grzela
Hadley
Hancock
Kosny
Goodwillie
Labelle
Agawa
Frater
Larson
Loach
McAughey
Montreal
Moen
Moggy
Cow
Neill
Montreal I.
Labonle
Peever
Home
Raaflaub
Runnalls
Running
Schembri
Scriven
Sherratt
Montreal River Harbour
Theano Pt.
Tronsen
Vibert
Way-White
Wlasy
Bracci
Goulais
Butcher
Ple. aux Mines
Kincaid
Nicolet
Norberg
Olsen
Dayieaux
Desbiens
Gapp
Gaudry
River
Hoffman
Mamainse Pt.
Ryan
Palmer
Wishart
Brûlé
Grenoble
Dablon
Lunkie
Nahwegezhic
Pine
Fisher
Tilley
Archibald
Marne
LaVerendrye
Goulais
Lamming
Menard
Batchawana Bay
I.R.15E
Corbeil Pt.
Hynes
Batchawana Bay
Tupper
Shields
Gaudette
Ley
Havilland
Kars
Fenwick
Van
Deroche
Searchmont
Isle
0
10
20
km

Figure 82.1. *Location of study area.*

This project A.8.1. is part of the five year Canada-Ontario 1985 Mineral Development Agreement (COMDA), a subsidiary agreement to the Economic and Regional Development Agreement (ERDA) signed by the governments of Canada and Ontario.

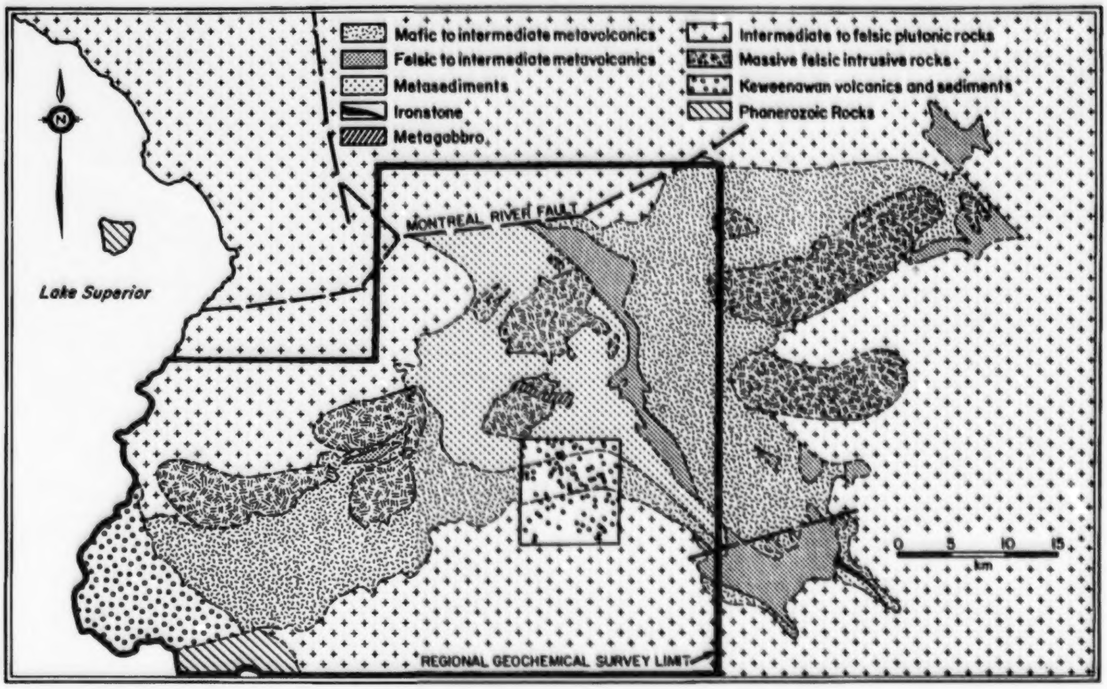
Mafic to intermediate metavolcanics
Felsic to intermediate metavolcanics
Metasediments
Ironstone
Metagabbro
Intermediate to felsic plutonic rocks
Massive felsic intrusive rocks
Keweenawan volcanics and sediments
Phanerozoic Rocks
N
Lake Superior
MONTREAL RIVER FAULT
REGIONAL GEOCHEMICAL SURVEY LIMIT
0
5
10
15
km

Figure 82.2. *Generalized geological map of the Batchawana Synoptic Project area showing the limit of the regional geochemical survey and, as an inset, the sample density for lake waters and sediments.*

some areas which are relatively inaccessible and poorly explored (Figure 82.2).

OBJECTIVES

The objectives of the survey are:

1. to collect water and pre–Ambrosia (i.e. over 100 years old; *see* Fortescue and Stahl 1987b) lake sediment core material from at least one point in all lakes and ponds accessible by helicopter within the 2475 km² area included in the geochemical survey
2. to provide in hard copy (and in computer readable form) data on pH, and on the Ca and Mg contents of the water samples; and data on levels of Ag, Al, As, Au, Ba, Be, Br, Ca, Cr, Cu, Co, Fe, Hf, K, La, Lu, Mg, Mn, Mo, Na, Ni, P, Pb, Sb, Sc, Sr, Ta, Th, Ti, U, V, W, and Zn in pre–Ambrosia lake sediment samples collected from the entire area covered by the regional geochemical survey
3. to provide a summary of the geochemical behaviour of elements occurring in these samples that are of importance to mineral exploration, using univariate, bivariate, and multivariate statistical analyses of the geochemical data

GEOLOGICAL SETTING OF THE BATCHAWANA REGIONAL GEOCHEMICAL MAP AREA

The Batchawana regional geochemical map area includes all of Raaflaub, Runnalls, Running, Tolmonen, Tronsen, Vibert, Way White, Norberg, Olsen, Davieaux, Desbiens, Wishart, Brulé, Grenoble, Dablon, Kincaid, Nicolet, Ryan, and Palmer townships; and parts of Larsen, Loach, McAughey, McParland, Home, Tilley, Archibald, Marne, Slater, Smilsky, Herrick, and Fisher townships (*see* Figure 82.1).

The bedrock lithology of the entire Batchawana Greenstone Belt is summarized on Figure 82.2. Briefly, Grunsky (1981) divided the area into three major geological domains. These are the Archean metavolcanic, metasedimentary supracrustal domain; the Archean felsic plutonic (including gneissic and migmatitic) domain; and the Keweenawan volcanic, sedimentary, felsite, and mafic intrusive domain (Figure 82.2). It is evident from Figure 82.2 that the regional geochemical survey covers areas underlain by all of the three geological domains. More detailed geological information on the area may be obtained from Grunsky (1981, 1982), Siragusa (1986), and the recently released 1:50 000 scale geological maps of the Batchawana Synoptic area (Grunsky 1987a, 1987b).

METHODOLOGY

The sampling of lake sediments and waters for the Batchawana regional geochemical survey was completed during 1987 and 1988, using a crew of two and a Bell 206 helicopter mounted on floats. Sampling at each site involved the collection of one, or more, lake sediment cores plus the collection of a 1 L water sample. Surface water samples were collected from sites less than 5 m deep and deeper waters were sampled using a plastic tube sampler which collected water down to 5 m.

The feasibility of collecting lake sediment cores for regional geochemical surveys was established in 1986 (Fortescue and Stahl 1987b). During the 1987 survey, sediment core sample collection involved two stages, the collection of cores on the helicopter float and the extrusion of the cores at base camp. In 1988, the cores were extruded on the helicopter float immediately after collection when a sample of pre–Ambrosia material was obtained.

REVISED LAKE SEDIMENT SAMPLING

The technique employed to collect and extrude lake sediment cores on a helicopter float is illustrated in three photographs included as Photo 82.1. Photo 82.1a illustrates the equipment required for the collection and extrusion of lake sediment cores on a helicopter float. In Photo 82.1a the gravity sampler (A) is connected to a spool of rope (B); the acrylic sampling tube (C) is a push fit inside the gravity sampler. The PVC extrusion tube (D) is anchored at one end on the helicopter float. During sampling, a rubber bung (E) is inserted into the sample tube after the core has been hauled to just below the water surface. The sample tube (including the core and bung) is then removed from the sampler and mounted onto the extrusion tube. The sample tube is then pushed down the outside of the extrusion tube; the bung acts as a piston forcing first water, and then the core, out of the sample tube. The extruded sample is then retained in a plastic bag (F). Photo 82.1b shows the gravity sampler, complete with sample tube ready for sampling. Photo 82.1c shows a sample being extruded, using the bung as a piston (the letters correspond to the descriptions for Photo 82.1a).

During the Batchawana survey, only the sediment deeper than 18 cm (i.e. "pre–Ambrosia"; *see* Fortescue and Stahl 1987a) was retained for chemical analysis, unlike the procedure used in the Magpie River area (Fortescue and Nakashima, this volume), where both the pre– and post–Ambrosia samples were obtained from the on–float extrusion of cores.

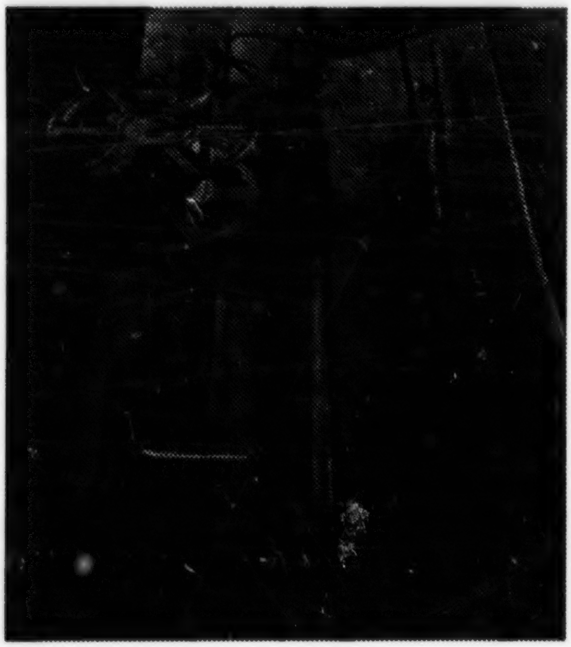

Photo 82.1a. *The equipment for lake sediment core sampling and extrusion which is normally used on a helicopter float (for an explanation of the letters in the photographs, refer to the text).*

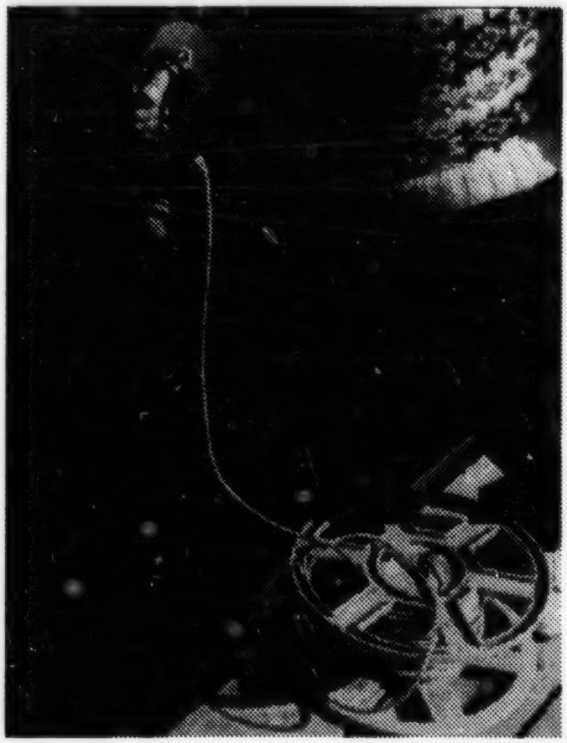

Photo 82.1b. *For an explanation of the letters in the photographs, refer to the text.*

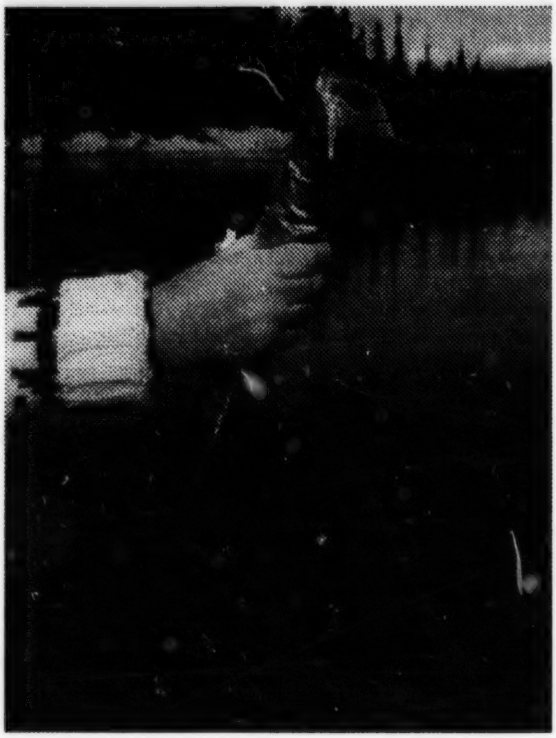

Photo 82.1c. *For an explanation of the letters in the photographs, refer to the text.*

It has been found by experience that, using this technique on a helicopter float, as many as 10 pre-Ambrosia samples can be obtained per hour. During the 1988 Batchawana regional geochemical survey, sample collection at the rate of 60 to 70 samples per day was common; this required about 8 hours of helicopter time, which included ferry time between the base camp and the area being sampled.

PROGRESS SO FAR

By the end of the first week in September, all 947 sediment and water samples collected during 1988 had been passed to laboratories for chemical analysis. It is anticipated that the chemical analysis of the samples will be completed by the end of January 1989, and that the report describing the entire Batchawana geochemical survey will be completed twelve months later.

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1986: Geology of the Batchawana-Pangis Area, District of Algoma; Ontario Geological Survey Report 243, 56p. Accompanied by Maps 2479 and 2480, scale 1:31 680 or 1 inch to 1/2 mile.

83. Project Number 87–26. The Use of the Geochemistry of Long Lake Sediment Cores for Verification of Regional Geochemical Results: Goudreau Lake Area, District of Algoma

John A.C. Fortescue

Research Geochemist, Geophysics/Geochemistry Section, Ontario Geological Survey, Toronto.

INTRODUCTION

During June 1987, a regional geochemical survey, based on lake sediments and waters, was completed in a 500 km² area centred on Goudreau Lake some 40 km northeast of Wawa (Fortescue and Stahl 1987a) (Figure 83.1). To avoid the possibility of fallout from the Wawa sintering plant influencing the results, the lake sediment geochemical data was obtained from sediment which was laid down over 100 years ago (i.e. in "pre–Ambrosia" time (Fortescue and Stahl 1987b)). Some of these "pre–Ambrosia" samples were found to have positive geochemical results which needed verification prior to the publication of the regional lake sediment survey.

The verification procedure is based on the geochemistry of segments of long, lake sediment cores which extend from the surficial sediment at the bottom of the lake into the mineral matter below the zone of organic matter. The geochemistry of lake sediment cores of this type had been examined previously by the Ontario Geological Survey (Fortescue 1986) in the Wawa area. When the historical succession of plant cover types since glaciation (9000 years B.P. as determined by palynology) were related to the distribution of 14 elements in segments of long cores, certain interesting geochemical relationships were found.

This experience indicated that the distribution of an element in a long, lake sediment core was usually relatively uniform from 25 cm below the bottom of the lake to a metre depth or further. The top 25 cm portion of the core included the "post–Ambrosia" material, laid down during the past 100 years, which in the Goudreau Lake area is contaminated by fallout from the Wawa smelter. As the 1987 geochemical survey was based on short core "pre–Ambrosia" sediment, it was reasoned that long cores taken at the same sample points as those found to have positive geochemistry in the regional survey would provide a basis for verification of the regional survey results.

In order to test this hypothesis, 13 long cores were collected from the Goudreau Lake area during March 1988 by a four–man crew including the writer, an assistant from the Ontario Geological Sur-

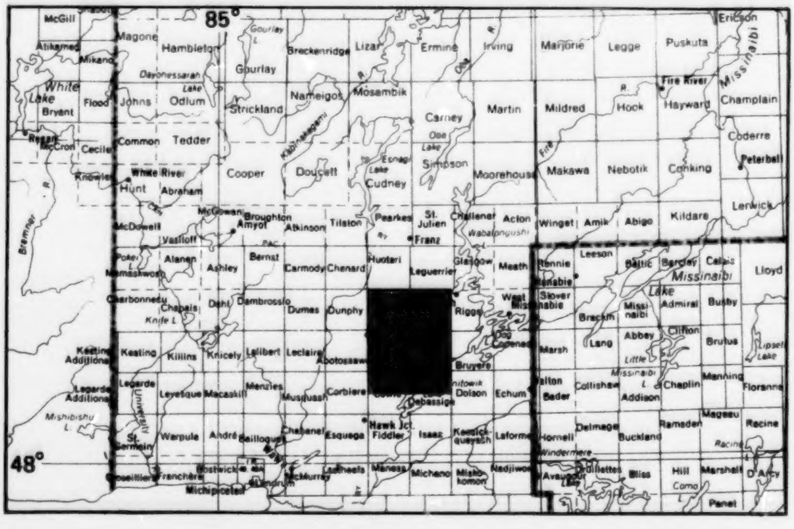

85°
48°
McGill
Magone
Hambleton
Gourlay
Breckenridge
Lizar
Ermine
Irving
Marjorie
Legge
Puskuta
Ericson
Missinaibi
Atikameg
Mikano
Dayohessarah Lake
White Lake
Bryant
Flood
Johns
Odlum
Strickland
Nameigos
Mosambik
Carney
Martin
Mildred
Hook
Fire River
Hayward
Champlain
Common
Tedder
Obe Lake
Simpson
Cecile
Coderre
Peterbell
Knowles
White River
Cooper
Doucett
Esnagi Lake
Cudney
Moorehouse
Makawa
Nebotik
Conking
Hunt
Abraham
Lerwick
McDowell
Broughton
Amyot
Atkinson
Tilston
Pearkes
St. Julien
Franz
Challener
Acton
Wabatongushi
Winget
Amik
Abigo
Kildare
Vasiloff
Alanen
Ashley
Bernst
Carmody
Chenard
Huotari
Leguerrier
Glasgow
Meath
Rennie
Leeson
Baltic
Barclay
Calais
Lloyd
Missinaibi
Charbonneau
Chapais
Knife L.
Dahl
Dambrossio
Dumas
Dunphy
Riggs
West
Stover
Brackin
Admiral
Busby
Keating Addition
Keating
Killins
Knicely
Lalibert
Leclaire
Abotossaway
Lang
Abbey
Clifton
Brutus
Lipsett Lake
Bruyere
Marsh
Little Missinaibi L.
Manning
Legarde Addition
Legarde
Levesque
Macaskill
Menzies
Musquash
Corbiere
Dolson
Echum
Bader
Collishaw
Addison
Chaplin
Florance
Mishibishu L.
University
St. Germain
Warpoole
André
Chabanel
Esquega
Hawk Jct.
Fiddler
Isaac
Laforme
Hornell
Delmage
Buckland
Ramsden
Racine
Mageau
Windermere
Bostwick
Michipicoten
Michano
Nadjiwon
Bliss
Hill
Como L.
Marshall
D'Arcy
Panel

Figure 83.1. *Location map for the Goudreau Lake area. Scale: 1:1 584 000 or 1 inch to 25 miles.*

vey, and a two-man drilling crew from Metaprobe Inc. of Picton, Ontario, working under contract to the Ontario Geological Survey. The long cores were sectioned soon after collection and the segments passed to Chemex Labs of Mississauga, Ontario, (also under contract to the Ontario Geological Survey) for the determination of 32 elements in each sample. This research is currently being prepared for publication. The purpose of this report is to outline the methodology employed to obtain the long cores and to describe the behaviour of selected elements in each of four of the long cores in order to illustrate the verification procedure.

OBJECTIVES

The objectives of the project were

1. to establish a methodology for the routine collection of undisturbed, long, lake sediment cores from frozen lakes in the Goudreau Lake area and
2. to describe vertical distribution patterns for elements in the long cores in order to verify positive geochemical results obtained from the same sample points during the 1987 regional geochemical survey of the Goudreau Lake area.

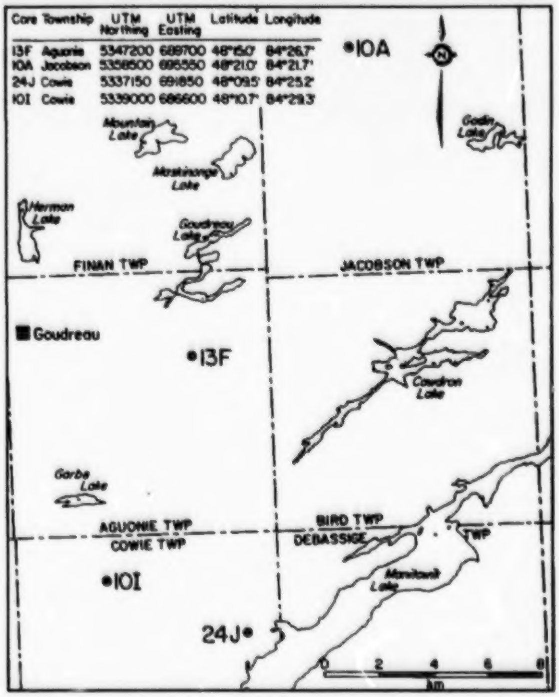
GEOLOGICAL SETTING OF THE GOUDREAU LAKE AREA

The Goudreau Lake area includes almost all of Finan, Jacobson, Aguonie, and Bird townships together with the northern part of Cowie and Debassige townships. The area is underlain almost entirely by Archean greenstones and associated rocks of the Wawa Greenstone Belt and a small area of the surrounding granitic terrain. More details of the bedrock geology of the area are provided by Fortescue and Stahl (1987a), Sage (1985, 1987), Arias and Heather (1987), and Heather and Arias (1987) together with other reports in this volume.

FIELD WORK

In March 1988, the drilling crew assembled at Wawa. The drillers used a vibro-core drilling rig which is small, relatively light, portable in a helicopter, and suitable for the collection of organic cores from the bottom of lakes with a depth of water to a maximum of 20 m. The crew and equipment were transported to drill sites in an A-Star helicopter. This helicopter was particularly convenient because the drill rod could be stacked across the rear of the cabin at the same time as the drill press was slung underneath the aircraft.

The drill sites were chosen on the basis of two criteria. One was that the sites had positive geochemical results for elements of interest in the 1987 survey and the other was that the depth of water from which the 1987 samples were collected did not exceed 20 m. The positions of the four drill sites described here are included in Figure 83.2.



Core	Township	UTM Northing	UTM Easting	Latitude	Longitude
13F	Aguonie	5347200	689700	48°15.0'	84°26.7'
10A	Jacobson	5358500	695550	48°21.0'	84°21.7'
24J	Cowie	5337150	691850	48°09.5'	84°25.2'
10I	Cowie	5339000	686600	48°10.7'	84°29.3'

Figure 83.2. *Positions for sediment cores in the Goudreau Area.*

The drilling procedure at each lake sample site was as follows. During the first helicopter flight from the previous hole, the drill rod and the drill press together with two members of the crew were transported. The press was dropped near the site and the gear unloaded. Using an ice auger, a 15 cm diameter hole was cut through the ice and the depth of water checked using a depth sounder. The drill press was then assembled over the hole, and with the arrival of the remainder of the equipment on the second helicopter flight, drilling commenced. After trying several combinations of drill pipe and core barrels, it was found that collecting a core in a 2 inch diameter acrylic sample tube inside a stainless steel core barrel was the most effective. The 13 cores ranged in length from 42 inches to 180 inches and the water ranged in depth from 0 to 63 feet.

FOUR EXAMPLES OF THE VERIFICATION OF 1987 LAKE SEDIMENT RESULTS

DESCRIPTION OF THE 1987 RESULTS

An appraisal of the 1987 regional geochemical data from the Goudreau Lake area (obtained from "pre-Ambrosia" sediment) showed relatively high values for certain elements in some of the samples (Table

TABLE 83.1. SELECTED "PRE-AMBROSIA" GEOCHEMICAL DATA FROM THE 1987 REGIONAL GEOCHEMICAL SURVEY FOR FOUR SAMPLE SITES (ONE CONTROL (13F), ONE POSITIVE FOR La (10A), ONE POSITIVE FOR Cu (24J), AND ONE POSITIVE FOR Au (10I)).

CORE	L.O.I.	La	Cu	Mo	As	Au	Sb
13F	58.0	9	42	2.0	3	2	<0.2
10A	42.2	120	63	1.0	2	1	<0.2
24J	42.0	64	231	15.0	1	<8	<0.2
10I	46.2	15	84	2.0	36	12	1.7

83.1) and high background values in the others. Sample point 13F was chosen as a control site from which background geochemical data had been obtained for the elements under discussion. Positive values for one, or more, of lanthanum, copper, molybdenum, gold, arsenic, and antimony were found in the other three cores (Table 83.1).

DESCRIPTION OF THE 1988 LONG CORE RESULTS

Details of the geochemical results for elements of interest in the long cores collected from the sample sites listed in Table 83.1 are provided in Tables 83.2, 83.3, 83.4, and 83.5. In Tables 83.3, 83.4, and 83.5, the data listings for the elements which are not positive provide background information regarding their behaviour in long cores.

LONG CORE 13F (CONTROL)

In core 13F (Table 83.2), the loss on ignition (LOI) values are consistently higher than that listed in Table 83.1 for this sample site and suggest that the short and long cores were not collected at exactly the same location in the lake. Otherwise, the levels for the elements are generally similar in the 1987 and 1988 samples. The data listings for the elements down core 13F show that, except for copper, the levels for the elements selected are remarkably similar during the 9000 year sedimentation period. The copper data has a distinct peak in the bottom third of the core. This pattern is similar to copper peaks

TABLE 83.2. SELECTED GEOCHEMICAL DATA FROM CORE 13F.

Depth (inches)	L.O.I. (%)	La (ppm)	Cu (ppm)	Mo (ppm)	Au (ppb)	As (ppm)	Sb (ppm)
6	68.4	38	61	3	<5	4	<0.2
12	61.4	38	63	3	<5	6	<0.2
18	57.0	37	66	2	<5	4	<0.2
24	57.4	32	67	3	<5	4	<0.2
30	46.8	35	58	2	<5	4	<0.2
36	62.2	46	69	1	<5	4	<0.2
42	72.6	60	84	2	<5	7	<0.2
48	66.0	38	78	3	<5	7	<0.2
54	72.0	39	83	5	<5	6	<0.2
60	66.8	48	90	3	<5	5	<0.2
66	60.0	41	78	5	<5	5	0.4
72	59.6	52	85	4	<5	6	<0.2
78	58.8	37	69	3	<5	7	<0.2
84	60.4	42	74	3	<5	7	0.2
90	60.8	36	74	2	<5	6	0.2
114	49.4	54	138	5	5	7	<0.2
120	59.8	92	205	4	<5	9	0.2
126	65.6	48	166	2	5	5	<0.2
132	69.2	26	142	4	<5	5	<0.2
138	72.0	15	121	3	<5	3	0.2
144	68.2	17	115	5	<5	4	0.2
*150	30.0	21	73	2	16	3	<0.2
156	1.0	20	13	1	<5	<1	<0.2
162	0.4	16	17	1	<5	<1	<0.2
168	0.6	13	20	<1	<5	1	<0.2

** – transition from organic to mineral matter*

TABLE 83.3. SELECTED GEOCHEMICAL DATA FROM CORE 10A.

Depth (inches)	L.O.I. (%)	La (ppm)	Cu (ppm)	Mo (ppm)	Au (ppb)	As (ppm)	Sb (ppm)
6	27.4	110	58	1	<5	4	<0.2
12	34.4	130	63	1	<5	4	<0.2
18	36.0	120	53	1	<5	4	<0.2
24	43.0	150	64	2	<5	4	<0.2
30	41.6	150	65	1	<5	4	0.2
36	39.6	130	63	2	<5	2	<0.2
42	40.8	160	78	2	<5	3	<0.2
48	40.2	170	83	2	<5	3	<0.2
54	37.4	150	77	1	<5	1	<0.2
60	41.0	210	108	1	6	2	<0.2
66	36.0	170	91	2	<5	2	<0.2
72	40.4	220	124	3	<5	4	<0.2
78	40.8	280	147	2	<5	5	<0.2
84	42.8	350	202	4	<5	5	<0.2
90	48.8	390	316	5	<5	6	<0.2
96	47.2	400	377	3	<5	6	<0.2
102	42.8	430	439	5	<5	6	<0.2
108	35.6	350	411	6	<5	5	<0.2
*114	20.4	260	471	7	<5	3	<0.2
120	5.8	100	198	2	<5	1	<0.2

* *– transition from organic to mineral matter.*

TABLE 83.4. SELECTED GEOCHEMICAL DATA FROM CORE 24J.

Depth (inches)	L.O.I. (%)	La (ppm)	Cu (ppm)	Mo (ppm)	Au (ppb)	As (ppm)	Sb (ppm)
6	n.s.s.	74	196	4	<5	2	0.2
12	38.6	74	192	3	5	2	0.2
18	39.8	90	244	4	<5	2	<0.2
24	42.8	97	272	4	<5	1	<0.2
30	43.2	100	280	5	<5	1	<0.2
36	42.6	100	284	5	<5	1	<0.2
42	45.2	110	374	10	<5	1	<0.2
48	36.8	106	412	19	<5	<1	<0.2
54	42.2	94	474	25	<5	1	<0.2
60	44.4	83	598	39	7	2	0.2
66	27.2	49	397	32	<5	2	<0.2
72	34.6	54	521	40	<5	3	0.2
78	49.6	64	926	65	5	3	0.3
84	44.6	66	1335	46	11	5	0.4
90	55.0	58	1810	115	11	6	0.6
*96	20.4	30	673	64	5	4	0.3
102	1.4	16	66	13	<5	1	<0.2
108	0.4	15	36	2	<5	2	<0.2
114	0.2	12	53	1	<5	3	<0.2
120	1.0	12	95	5	<5	1	0.1

* *– transition from organic to mineral matter.*

discovered in six other long cores from Central Ontario described by Fortescue (1986). These were explained, on the basis of palynological information, by changes in the plant cover type due to climatic variations soon after the lakes were formed. The changes were from coniferous forest (spruce) to deciduous forest (birch) and then back to coniferous forest (pine). Evidence of this copper peak is also found in the other three cores (Tables 83.3, 83.4, and 83.5).

LONG CORES 10A, 24J, AND 10I

Geochemical data for 6 elements (La, Cu, Mo, Au, As, and Sb) out of the 32 determined in the long

TABLE 83.5. SELECTED GEOCHEMICAL DATA FROM CORE 10I.

Depth (inches)	L.O.I. (%)	La (ppm)	Cu (ppm)	Mo (ppm)	Au (ppb)	As (ppm)	Sb (ppm)
6	46.2	18	75	1	7	22	2.0
12	47.4	19	89	1	6	37	2.0
18	45.6	20	82	1	6	45	2.2
24	45.0	22	93	1	11	53	2.6
30	43.6	17	87	1	5	48	2.6
36	44.6	17	88	2	5	36	2.3
42	42.4	22	94	2	7	32	2.0
48	44.4	21	96	2	7	36	2.4
54	45.2	21	107	1	<5	36	2.2
60	45.2	20	98	2	<5	33	2.1
66	45.4	18	105	1	<5	30	1.8
72	46.4	19	110	2	6	35	1.9
78	48.8	19	109	3	<5	42	2.5
84	49.2	22	111	2	<5	50	2.5
90	46.0	23	115	3	<5	53	3.0
96	51.4	24	157	4	5	75	3.3
102	52.2	22	185	4	7	90	4.1
108	51.6	23	166	4	5	98	5.0
114	53.2	22	203	5	6	98	5.0
120	55.0	24	271	4	11	120	5.0
126	49.4	26	221	3	6	160	4.0
132	36.0	23	127	3	5	110	3.0
*138	5.0	17	30	1	<5	9	<0.2
144	0.8	13	12	<1	<5	2	<0.2
150	0.8	13	13	1	<5	1	<0.2
156	1.6	12	14	<1	<5	1	<0.2
162	1.4	13	12	<1	<5	2	<0.2
168	0.6	15	13	<1	<5	3	<0.2
174	0.6	13	18	1	<5	2	0.3
180	0.2	14	23	1	<5	4	<0.2

* – *transition from organic to mineral matter.*

cores collected in March 1988, are listed in full on Tables 83.3, 83.4, and 83.5 together with data on core sample depths and LOI. The range of depth of the cores is from 4.75 m in core 24J (Table 83.4), to 7.25 m in core 10I (Table 83.5). One reason for the choice of these three cores for discussion here is that, like core 13F, they all extend through the entire organic layer into the mineral matter beneath. Incidentally, several of the long cores in the Goudreau Lake series were recovered without a mineral layer either because the sampler failed to penetrate the mineral layer, or because it failed to retain samples of the mineral layer during extraction owing to the coarse grain size of the material.

The LOI of the organic matter is usually remarkably uniform down a core until the mineral layer is reached (Tables 83.2, 83.3, 83.4 and 83.5). This is important because it indicates that the organic layer in the cores was uniform during the 9000 years in which sedimentation took place, thereby providing a suitable medium on which to base descriptions of the element patterns in a core.

The distribution patterns for the six elements in the four long cores just described were compared.

Lanthanum

The lanthanum level in control core 13F (Table 83.2) varies between 15 and 92 ppm in the organic zone. Below this, in the transition zone and the mineral zone underlying it, the level is consistently below 20 ppm. In core 10I (Table 83.5), levels for lanthanum are even lower with a range between 17 and 26 ppm in the organic zone and 12 to 15 ppm in the mineral zone. The lanthanum level in core 24J is more variable with a low at the top and bottom of the core and higher values in between (Table 83.4). Lanthanum values range between 12 and 16 ppm in the mineral zone of this core.

Attention was drawn to the relatively high lanthanum level of organic sediment in core 10A during the 1987 survey when 120 ppm of this element was recorded in the "pre–Ambrosia" sediment (Table 83.1). Detailed data for lanthanum in the long core from this lake (Table 83.3) shows a range from 110 ppm at the top of the core to 430 ppm at a depth of 102 inches. The level of lanthanum in the single sample taken from the mineral zone in this core was 100 ppm.

The presence of relatively high lanthanum values in the single 1987 short core "pre–Ambrosia" sample was verified by the data from the top of the long core. The lanthanum content of the organic sediment was also seen to increase fourfold further down the core. At 100 ppm, the level of lanthanum in the mineral zone of this core was also relatively high. The level of copper, molybdenum, and arsenic also increases toward the bottom of this core. This pattern is absent for gold and antimony.

It is concluded that the positive lanthanum value found in the 1987 survey was verified by the information obtained from the long core. The long–core data also provided additional information regarding the elements of interest which might be pertinent to mineral exploration in the area.

Copper and Molybdenum

Background levels of copper and molybdenum found in the 1987 survey from 13F, 10A, and 10I (Table 83.1) were verified by the data obtained from the upper parts of the long cores obtained from these lakes (Tables 83.2, 83.3, and 83.5). Towards the bottom of the organic zone in these cores, relatively high copper values were found as described previously.

A level of 231 ppm copper in the 1987 "pre–Ambrosia" sample from 24J was clearly anomalous with the normal level of this element in "pre–Ambrosia" sediment (Table 83.1). The copper data obtained from the organic zone of the long core obtained from this lake (listed on Table 83.4) confirms this high value. In addition, it shows a level 1810 ppm at the base of the organic zone although the copper is relatively low (36 to 95 ppm) in the underlying mineral material. What is particularly important from the mineral exploration viewpoint is the range of molybdenum values in this core which range from 3 ppm at the top to 115 ppm at the bottom of the organic layer. Levels for gold, arsenic, and antimony also increase slightly at the bottom of the organic layer in this core (Table 83.4).

It is concluded that the geochemical data obtained from the 24J long core verified the regional geochemical results for copper and in addition provided valuable information on the levels of molybdenum and other elements in the lower part of the core. These data suggest that there may be a polymetallic source of copper, molybdenum, and gold in, or near to, the lake.

Gold, Arsenic, and Antimony

Background values for gold, arsenic, and antimony were found in cores 13F and 10A and these results provide a good example of the background levels for these elements in the Goudreau Lake area. In core 24J, the results were similar at the top of the core but, as described above, levels for all three elements increased significantly at the bottom of the organic layer.

The levels of arsenic and antimony were consistently higher in core 10I compared with the other cores (Table 83.5). These data parallel down core the previous results from the regional survey (Table 83.1). The levels of copper, and to a lesser extent molybdenum, also increase toward the bottom of core 10I.

The gold results for long core 10I were disappointing because they were consistently lower than those found in 1987. Briefly, gold was detected in the 5 to 11 ppb range in 16 out of 22 of the 10I organic zone samples and in none of the 7 samples taken from the underlying mineral matter.

The long–core data confirmed the positive values for arsenic, antimony, and gold found in the 1987 survey; the source of these elements has been the same during the entire 9000 year period of sedimentation. The rate of input of these elements to the sediment appeared to have been more rapid during the early stages of sedimentation compared with later on.

GENERAL CONCLUSIONS

1) Collectively, the data from the four long, lake sediment cores described here demonstrates how well the results from the 1988 vibro core drilling verify positive geochemical results obtained from a regional lake sediment survey based on "pre–Ambrosia" material in the Goudreau Lake area in 1987.
2) A comparison of the multi–element geochemistry of the organic and mineral zones of long cores taken from the Goudreau Lake area indicates, but does not prove, that the positive geochemical results obtained in the lower part of the cores results from a migration of elements into the lakes during the deposition of the organic material and not from an upwelling of water from the underlying mineral zone.
3) The high copper and molybdenum results found in the bottom of core 24J are likely to be of interest in mineral exploration and should be verified by further work.

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84. Project Number 88–31. A Regional Geochemical Survey of the Magpie River Area, District of Algoma

John A.C. Fortescue[1] **and Arthur Nakashima**[2]

[1]Research Geochemist, Geophysics/Geochemistry Section, Ontario Geological Survey, Toronto.

[2]Geological Assistant, Geophysics/Geochemistry Section, Ontario Geological Survey, Toronto.

INTRODUCTION

During September 1988, a small–scale regional geochemical survey, based on lake sediments and waters, was completed in a 400 km² area in the vicinity of the Magpie River, situated 30 km north of Wawa, Ontario (Figure 84.1).

The purpose of regional geochemical surveys of this type is to provide verified geochemical information, which is of direct importance in mineral exploration. The Magpie River area is of particular interest to explorationists at the present time, because it lies to the west of the Goudreau Lake area (Fortescue and Stahl 1987) where new gold deposits are currently being developed. A geochemical survey of the Magpie River area is important, because parts of the area are covered by surficial deposits where outcrops of bedrock are relatively rare. Like the Goudreau Lake geochemical survey which was completed last year, the Magpie River survey can be considered as a part of an orientation survey for regional geochemical coverage of the entire Wawa Greenstone Belt at some future time.

OBJECTIVES

The objectives of the regional geochemical survey were:

1. To collect water and lake sediment core material from most lakes and ponds accessible by helicopter in the 500 km² Magpie River area.
2. To provide both in hard copy and in computer readable form, data for the pH, Ca, and Mg content of the water samples and the levels of Ag, Al, As, Au, Ba, Be, Br, Ca, Cr, Cu, Co, Fe, Hf, K, La, Lu, Mg, Mn, Mo, Na, Ni, P, Pb, Sb, Sc, Sr, Ta, Th, Ti, U, V, W, and Zn, in pre– and post–Ambrosia lake sediment core material collected from sample sites in the Magpie River area.
3. To provide a summary of the geochemical behaviour of elements, which are of interest in mineral exploration in the Magpie River area. This is achieved using uni–variate, bi–variate, and multi–variate statistical analyses of the geochemical data obtained from the water and pre–Ambrosia lake sediment samples.

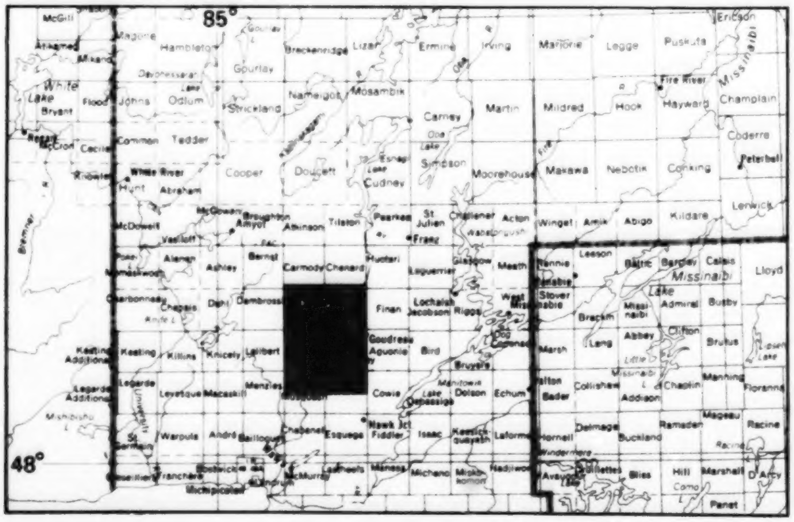

Figure 84.1. *Location map for the Magpie River regional geochemical survey area. Scale: 1:1 584 000 or 1 inch to 25 miles.*

4. To contribute regional geochemical data to an experimental, interdisciplinary, geoscience Geographic Information System (GIS) project of the Wawa Greenstone Belt area, to include bedrock geology, Quaternary geology, geophysics, remote sensing, and mineral deposit study data sets.

GEOLOGICAL SETTING OF THE MAGPIE RIVER AREA

The Magpie River study area includes all of Dumas, Dunphy, Leclaire, and Abotossaway townships, together with parts of Musquash and Corbiere townships to the south and parts of Carmody and Chenard townships to the north. This area is underlain almost entirely by Archean greenstones and associated rocks of the Wawa Greenstone Belt. The contact between rocks of the Wawa Greenstone Belt and the surrounding granitic terrain crosses the central part of Dumas and Dunphy townships in a westerly direction. Carmody and Chenard townships are entirely underlain by granitic rocks. The remainder of the Magpie River area is underlain by the rocks of the Wawa Greenstone Belt. The lithology and the structure of the greenstone belt in the Magpie River area and the Goudreau Lake area to the east is particularly complex (Sage 1985).

Gartner and McQuay (1979) provided an introduction to the Quaternary geology of the Magpie River area and the Goudreau Lake area to the east. They note that the ice advance from the north–northeast deposited a thin mantle of stony, sandy till over much of the bedrock in the area. When the ice retreated, it left a number of Quaternary deposits, which mark the occurrence of ancient spillways and esker trains. Gartner and McQuay's map shows that in the southwestern Magpie River area, morainal features are more common than in the Goudreau Lake area farther east. Like the Goudreau Lake area, the Magpie River area has a number of relatively small patches of organic terrain distributed more or less at random over the entire area. The most significant Quaternary deposits in the Magpie River area are glaciofluvial outwash plains and eskers which occur in, and to the north of, Abotossaway and Leclaire townships.

In general, the bedrock and Quaternary geological conditions in the Magpie River area are favourable for a regional geochemical methodology based on lake sediments and waters. However, a complicating factor is the presence of a fume kill in the southeastern Magpie River area, which results from effects of atmospheric fallout from the Wawa sinter plant located to the south of the area surveyed. The sintering plant commenced operation in 1909. Since then, forest fires in the fume kill area have reduced significantly the vegetative cover in the area (Fortescue 1984). The regional geochemical survey is based upon the chemical analysis of "pre–Ambrosia" lake sediment (i.e. material obtained from below 18 cm depth in lake sediment cores which is usually over 100 years old), ensuring reliable geochemical data is obtained, in spite of the contamination of surface sediment with chemicals derived from smelter fallout. The results from the chemical analysis of the "post–Ambrosia" sediment core samples should provide detailed information on the composition of the atmospheric fallout from the Wawa and other smelters, which have been active in the Magpie River area.

FIELD WORK

In late September and early October 1988, a crew of two, using a float equipped Bell 206 helicopter, collected duplicate lake sediment cores and 1 litre water samples from 403 sample points situated in lakes and ponds in the Magpie River area. Duplicate lake sediment cores were collected from 40 to 50 sample points per day, and in each case the "post–Ambrosia" material was extruded and collected separately. Core extrusion was completed on the helicopter float as described previously (*see* Fortescue, this volume).

The determination of the pH of water samples collected during regional geochemical surveys is often difficult to standardize, largely because of relatively large differences in the temperature of lake waters at the time of sampling, and because of effects of the ambient air temperature during transport of water samples to the field base where the pH determination will be made.

During the Magpie River project, these problems were solved as follows. In order to standardize the temperature of the water samples prior to pH determinations, the samples were placed in a refrigerator directly after being unloaded from the helicopter. After a batch of water samples had been in the refrigerator overnight, the samples were taken one at a time to the pH meter for pH determination.

The pH determination of the Magpie River water samples was carried out using a Fisher Accumet 925 pH meter and a glass electrode, which was calibrated previously using buffers at pH 4.0 and pH 7.0. The pH meter was hooked up to a Corona PC portable computer. A computer program on the PC was used to control the pH meter and record the pH of each water sample automatically. This was recorded when the input from the pH meter had stabilized to within 0.01 of a pH unit for a period of 25 seconds. In this way it is believed that a standardized and comparable "field pH reading" was obtained for all the water samples collected in the Magpie River project and for a series of river water standards sequenced with the unknowns.

The calcium and magnesium in the water samples is to be determined in the Geoscience Laboratories of the Ontario Geological Survey in Toronto. Chemex Labs Ltd. of Mississauga, Ontario, under contract to the Ontario Geological Survey, will com-

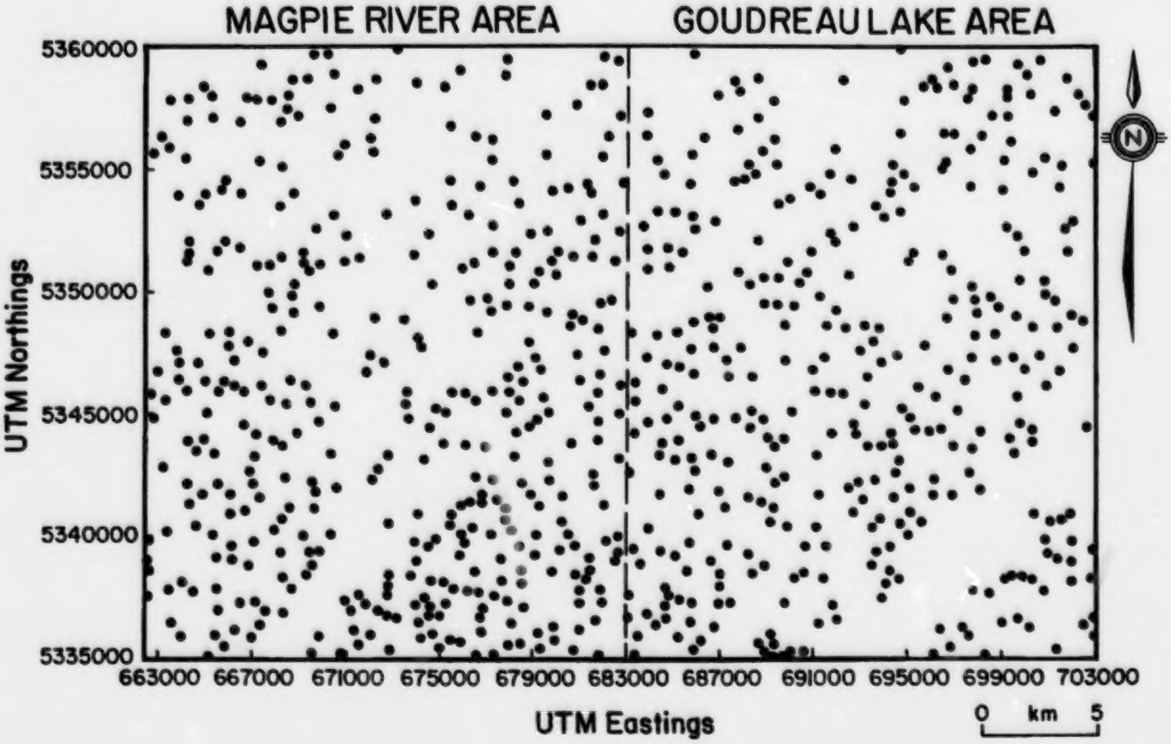

Figure 84.2. *The combined Magpie River/Goudreau Lake regional geochemical survey area showing lake sediment core/water sample point locations.*

plete the chemical analysis of the lake sediment samples for 32 elements.

SAMPLING INTENSITY

The area included in the Magpie River Regional Geochemical Survey was included in a reconnaissance geochemical survey completed jointly by the Ontario Geological Survey and the Geological Survey of Canada in 1978 (OGS-GSC 1979). During that survey, the samples were collected at an average density of 1 sample per 13 km^2 (5 square miles).

In the Gaudreau Lake Regional Geochemical Survey (Fortescue and Stahl 1987), which was completed in an area just to the east of the Magpie River Area, an average lake sample density of 1 sample per 1.4 km^2 was used. This compares with an average lake sample density of 1 sample per 1.22 km^2 in the Magpie River area. On Figure 84.2, the lake sample point patterns for the combined Goudreau Lake/Magpie River area are shown, in order to facilitate comparisons between the lake sampling coverage in the two areas.

PROGRESS SO FAR

The field sampling program at Magpie River has just been completed as this article goes to press. The sediment and water samples will be processed during the winter. The geochemical data obtained from the Magpie River survey will be released by the Ontario Geological Survey as soon as practical after it has been checked. High element values found in the Magpie River pre-Ambrosia material may be checked later on using long cores and the technique described elsewhere in Fortescue (this volume).

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Geoscience Laboratories Programs

85. Summary of Activities 1988, Geoscience Laboratories Section

Chris Riddle

Section Chief, Geoscience Laboratories Section, Ontario Geological Survey, Toronto.

INTRODUCTION

The Geoscience Laboratories of the Ontario Geological Survey were given Section status in 1987 and articles from the Section appear in this Summary of Activities for the first time. In addition to the production of routine geoanalytical data, the Laboratories Section performs analytical methods development work in support of Ontario Geological Survey programs.

This summary of scientific project work highlights recent achievements in the Laboratories' three subsections. To place these achievements in perspective, the interested reader is directed to the Laboratories' Manual and synopsis of "Analytical capabilities". A new edition of the former should be available in 1989; the latter is available from the Laboratories, on request.

MINERAL SCIENCE SUBSECTION

Peter Lightfoot, Supervisor of the Mineral Science Subsection, has been responsible for the introduction of new techniques related to routine production. He has also initiated work on a new method for the determination of the platinum group elements.

GRAIN SIZE ANALYSIS

Grain size analysis is used in the engineering classification of soils. Conventionally, the size distribution of particles with diameters in excess of 74 μ is determined by dry sieving, while the size distribution of particles with diameters less than 74 μ is determined by a sedimentation process using a hydrometer (ASTM procedure D422–54T). Both procedures are slow and require manual operation. In 1988, the Mineral Science Subsection acquired a particle size analysis system which allows the automated determination of grain size distributions from 2 to 700 μ. This first stage upgrade of grain size analysis has resulted in a doubling of productivity and the establishment of improved quality controls.

MINERAL SEPARATION

The use of toxic heavy organic liquids in the separation of mineral phases has been largely discontinued following the development of a non–toxic, high density agent (sodium polytungstate), a solution of which has a density adjustable up to 3.1 g/cm^3.

PLATINUM GROUP ELEMENTS

A procedure has been developed for the pre–concentration of the platinum group elements into a nickel sulphide fire assay button, together with a chemical procedure for the removal of the nickel sulphide to produce a noble metal concentrate. Access to the University of Toronto SLOWPOKE reactor and counting facilities permits routine neutron activation analysis of the concentrates for the entire spectrum of noble metals. Plans exist, in the Spectroscopy Subsection, for the development of an inductively–coupled–plasma mass–spectrometric (ICP–MS) method for the determination of the platinum group elements using these same noble metal concentrates.

Five new in–house reference materials have been developed for the platinum group elements. These were collected by James MacDonald, of the Precambrian

Section, with assistance from the Laboratories Section, and come from the Sudbury igneous complex, Ontario, and the Stillwater complex, Montana. Approximate concentration ranges (parts per billion) are as follows: gold, 300 to 6000; platinum, 700 to 7000; palladium, 1000 to 250 000; osmium, 10 to 300; iridium, 40 to 300; ruthenium, 60 to 750; rhodium, 150 to 2500.

Access to the SLOWPOKE facility also enables the Laboratories Section to perform routine determinations of tantalum and hafnium at the part per million level in rock samples.

MINERALOGY AND PETROLOGY

An X-Ray Diffraction (XRD) method, to replace the conventional Chittick method for the determination of calcite:dolomite ratios, is under development. Preliminary results on reference materials indicate that XRD will provide improved precision, accuracy, and productivity.

Routine access to electron microprobe facilities have been arranged with the University of Toronto to develop micromineralogical expertise within the Laboratories Section. Projects involving the analysis of mineral phases in samples submitted by staff geologists are in progress.

Methods have been developed within the Section for the separation and concentration of mineral phases from rock samples using a combination of techniques such as: isodynamic (Frantz) separation, specific gravity differentiation (high density reagents), and hand–picking of crystals. These methods have been applied to studies of two samples of Nipissing diabase with subsequent rare earth element analysis.

CHEMISTRY SUBSECTION

Chris Chan, Supervisor of the Chemistry Subsection, has participated in a wide-ranging review of sample preparation techniques, and has continued development of flow–injection analysis as applied to trace element analysis.

SAMPLE PREPARATION

Most methods for the determination of trace elements in geological materials require the preparation of a solution sample. The quality of analytical data for rock samples is therefore directly affected by the quality of the decomposition. Three sample preparation projects have been completed.

First, a common dissolution procedure, using acid digestion, has been developed for atomic absorption (AA) and inductively coupled plasma (ICP) based methods. This has increased productivity, and allows a single solution to be used for a variety of determinations.

Second, a procedure has been developed for "total decomposition" of rock samples in cases where the presence of intractable mineral phases renders acid digestion incomplete. This procedure involves acid digestion followed by fusion of the remaining residue. It produces a solution of relatively low salt content suitable for analysis by AA and ICP instrumentation.

Third, a robotic system has been installed to automate acid digestion.

FLOW INJECTION ANALYSIS

Flow–injection analysis is a technique that allows a discrete solution sample to be inserted into a carrier stream, without being diluted by the carrier, thereby enhancing analytical sensitivity. The technique has been successfully applied to the determination of selenium (Chan 1985) and chlorine (as per Fuge 1985) in rock samples, providing improved methods for these elements. No significant improvement over existing methodology resulted when the technique was applied to the determination of fluorine and mercury.

TRACE ELEMENT METHODS

A sensitive automated method for the determination of mercury using the technique of flameless AA (Kennedy and Crock 1987) has been applied to more than

50 international geological reference materials (Chan and Bina, in press). The results attest to the accuracy of the method and provide new data for those reference materials lacking well-defined mercury values.

In support of the current geochemistry program, a sensitive method for the determination of gold in waters, based on work of McHugh (1984), has been brought into routine operation. Gold is extracted into methyl isobutyl ketone and measured using graphite furnace AA spectrometry. The determination limit is 3 ng/l (0.003 ppb) which is approximately the background level of gold in natural waters.

SPECTROSCOPY SUBSECTION

Tony Vander Voet, Supervisor of the Spectroscopy Subsection, returned from a leave of absence during which he accepted a Canadian International Development Agency assignment in Bangkok as a trainer and consultant in analytical chemistry to the Department of Mineral Resources, Government of Thailand. While there he prepared a training manual and assisted in the development of quality control procedures.

Development work in the subsection has been focused on methods for the determination of trace elements using the techniques of ICP–Optical Emission Spectrometry (OES) and ICP–Mass Spectrometry (MS).

DEVELOPMENTS IN ICP–OES

A re–evaluation of ICP–OES methodology has resulted in revised procedures for the following elements, with the determination limits indicated: beryllium (1 ppm); scandium (2 ppm); strontium, vanadium, yttrium, cobalt, copper, nickel, and zinc (5 ppm); tungsten (50 ppm).

A new ICP–OES instrument, using a photodiode array detector system, has been under evaluation in the subsection. It has been applied to the determination of molybdenum, boron, and conventional geoanalytical multi–element packages.

DEVELOPMENTS IN ICP–MS

As one of the first analytical laboratories in the world to acquire an ICP–MS instrument, the Geoscience Laboratories Section has played a major role in geoanalytical applications of the technique and has published a review of the field (Riddle, Vander Voet, and Doherty 1988).

The Laboratories Section has developed a capability for high quality rare earth element (REE) analytical data (*see* Table 85.1), suitable for the production of chondrite plots. Initial work resulted in the first comprehensive ICP–MS study of REE in certified geological reference materials (Doherty and Vander Voet 1985). Doherty (in press) has now published the results of an internal standardization procedure which has increased significantly the accuracy and precision of ICP–MS measurements. The high quality of the data was confirmed by the international certification study of Ailsa Craig Granite (AC–E); the first such program to include ICP–MS data (Govindaraju 1987).

In addition to the REE, five other elements are now routinely determined by ICP–MS. These elements, with their corresponding determination limits in rock, are: thorium (50 ppb); uranium (50 ppb); lead (50 ppb); thallium (50 ppb); and tin (500 ppb).

OTHER ACTIVITIES

As part of a co–operative program with the Department of Mineral Resources of the Government of Thailand, the Mineral Sciences Subsection participated in training programs for two scientists from Bangkok. Srisopa Maranate worked in mineralogy; Wanachai Saisook in fire assay.

Wanachai Saisook was also trained in spectroscopic trace analysis using flameless AA, hydride generation AA, and graphite furnace AA in the Chemistry Subsection.

The Spectroscopy Subsection provided training to an Indonesian scientist, Dr. Wuryanto, sponsored by Atomic Energy of Canada.

TABLE 85.1. ICP-MS DETERMINATION LIMITS FOR RARE EARTH ELEMENTS INCLUDING CHONDRITE AND DETECTION LIMIT DATA.

Element	Chondrite Level	Determination Limit (ppm Rock)	Detection Limit (ppm Rock)
YTTRIUM	1.96	0.02	0.004
LANTHANUM	0.330	0.05	0.004
CERIUM	0.88	0.05	0.005
PRASEODYMIUM	0.11	0.05	0.004
NEODYMIUM	0.60	0.18	0.003
SAMARIUM	0.181	0.15	0.02
EUROPIUM	0.069	0.07	0.001
GADOLINIUM	0.249	0.14	0.018
TERBIUM	0.047	0.03	0.004
DYSPROSIUM	0.325	0.13	0.015
HOLMIUM	0.070	0.03	0.014
ERBIUM	0.200	0.10	0.005
THULIUM	0.030	0.03	0.015
YTTERBIUM	0.200	0.11	0.006
LUTETIUM	0.034	0.04	0.005

NOTE: Determination Limits refer to established, routine limits for the analytical method, based on quality control data. Detection limits refer to the optimal instrument performance possible.

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86. Project 88–01. The Determination of Trace Concentrations of Rare Earth Elements at the Geoscience Laboratories, Ontario Geological Survey

Anthony Vander Voet

Supervisor, Spectroscopy Laboratory, Geoscience Laboratories Section, Ontario Geological Survey.

INTRODUCTION

In order to establish a reliable analytical method for the determination of yttrium and the rare earth elements (REE), the Spectroscopy Sub–section of the Geoscience Laboratories, Ontario Geological Survey (GLOGS), has undertaken a number of developmental projects. This report surveys the work which has been carried out over the past ten years, and describes the current methods.

The stimulus for the development of analytical methods for the determination of trace level REE has been the use of these elements as indicators of petrogenetic processes. On the assumption that the original magmatic REE concentration distribution is approximated by that in chondritic meteorites, REE concentration data are normalized relative to chondrites and are plotted (as their logarithms) against atomic numbers. Where the distribution of REE approximates that in the original magma, chondrite plots are expected to exhibit relatively smooth slopes; anomalous changes in distribution are observed as sharp deviations in the plots. Because of the low chondrite normalizing values and the manner in which the data are treated for plotting, rare earth element concentrations in the range 0.02 to 100 ppm must be determined with unusually high precision and accuracy.

Much of the REE data appearing in geological or chemical literature have been obtained by instrumental neutron activation analysis (INAA), and although capable of providing excellent data, INAA is difficult, expensive, and subject to interferences. Other methods have included mass spectrometry (MS), X–ray fluorescence (XRF), atomic absorption spectroscopy (AAS), and emission spectrography. In the past ten years, inductively coupled plasma optical emission spectroscopy (ICP–OES) and, more recently, ICP mass spectrometry (ICP–MS) have been applied to REE determinations. ICP–OES has proven useful for the routine determination of REE because of its sensitivity, its ability to correct for spectral interferences, and its ability to perform simultaneous multi–element determinations. Although direct ICP–OES analysis of solutions of rocks and minerals (decomposed by acid digestion or fusion) can be applied to samples containing relatively high concentrations of REE, separation of the REE analytes from matrix elements is generally required for trace level (chondrite) determinations.

The excellent sensitivity, relative freedom from spectral interferences, and rapid sequential nature of ICP–MS permit REE determinations with detection limits at or below chondrite levels without REE separation or preconcentration. The application of ICP–MS to the analysis of geological materials was reviewed recently by C. Riddle, A. Vander Voet and W. Doherty (Geoscience Laboratories, OGS) in an article published in Geostandards Newsletter (Riddle *et al.* 1988).

Development work in the determination of REE at the GLOGS has included studies in XRF, ICP–OES, and ICP–MS. Considerable attention has been paid to the separation of REE from matrix elements for XRF and ICP–OES determinations by column ion exchange, high performance liquid chromatography (HPLC), and robotic techniques. Recently, a reliable, well–documented REE determination method for the ICP–MS has been developed, and is in current use for routine determinations. Full discussion of experimental details, reference material data, and work by other groups is reviewed in the Geoscience Laboratories' laboratory guide and manual (Riddle and Vander Voet, in preparation).

SAMPLE PREPARATION AND ANALYTE SEPARATION

Spectroscopic determinations of REE in geological matrices are generally complicated by: a) the generally low concentration levels of REE relative to instrument detection limits; b) the high concentrations of major elements and the presence of other minor and trace elements, which can be sources of chemical or spectral interference; and c) the lack of well–defined "usable" concentration values for certified reference (rock) materials (CRMs).

Rock matrices are among the most difficult sample systems for trace element analysis. The ideal rock analytical subsample is a fine, well–homogenized pulp of a representative field sample. Thus, for example, REE determinations in pressed powder pellets by XRF would be a preferred method (as it uses 5 g of rock pulp), were it not for the fact that XRF detection limits are not sufficiently low. Solid samples are also used in DC–Arc spectroscopy, and more recently, in direct solid, electrothermal vaporization, and arc and laser ablation techniques for ICP–OES and ICP–MS. The disadvantage of matrix (spectral) interferences, as well as the sample sizes used, limit their general application to the determination of REE in geological samples to samples containing relatively high analyte concentrations (Riddle *et al.* 1988).

Conventional ICP techniques employ solution nebulization to deliver the sample to the plasma. The requirement for total decomposition of samples can present some major problems, especially in the determination of REE. Low temperature acid digestion (using HF, $HClO_4$, and either HNO_3 or HCl) is the most popular method of sample decomposition, and is used by many laboratories, including those at the USGS (Crock and Lichte 1982) and the GLOGS (Bolton *et al.* 1983; Aulis *et al.* 1985; Doherty and Vander Voet 1985). This technique is generally satisfactory, except where the rock contains acid–resistant minerals, e.g. zircons. Although fusion techniques can decompose most rocks and minerals effectively (including zircons), they introduce additional total dissolved solids, resulting in possible deleterious transport effects in solution nebulization to flames and plasmas, and deterioration of detection limits.

In order to minimize matrix problems and simplify the determination of REE, it has been customary to separate the REE analytes from the matrix elements, thereby preconcentrating the analytes and overcoming limitations in instrumental detection limits. Separation techniques have included chemical separations, solvent extraction, ion exchange, and high performance liquid chromatography (HPLC). The popular cation exchange procedure is based on the preference of the trivalent REE ions for sites on a cation resin (conditioned with an acid medium). Dilute acid (HCl or HNO_3) is used to elute most of the matrix ions from the column. REE ions are removed at higher acid concentrations (6 to 8 *N* HCl or HNO_3). Ion exchange was used for the separation and preconcentration of REE for XRF analysis by Eby (1972), employing Dowex 50W–X8 resin and HCl. In this separation, all the cations except scandium, barium, yttrium, thorium, zirconium, and the REE could be eluted with the dilute acid. Experiments at the GLOGS showed that the separation was relatively inefficient, i.e. wide ion "band widths", especially for calcium and strontium. Similar ion exchange procedures were followed by other groups including Strelow and Jackson (1974), Walsh *et al.* (1981), and Brenner *et al.* (1984) for their ICP studies. At the United States Geological Survey (USGS) laboratories, Crock and Lichte (1982) (*see* also Crock, Lichte and Wildeman 1984) also used cation exchange separation, but found HNO_3 to be more efficient in removing matrix ions, including calcium and barium, in the first step. Iron, which was retained on the column, even after elution with concentrated acid, was removed by an anion exchange step with HCl. Analysts at the GLOGS adapted the separation scheme proposed by Eby (1972) for XRF work, modifying it for ICP–OES (Bolton *et al.* 1983). They further modified the separation in later work, using both dilute HCl and HNO_3 in the first step, and concentrated HNO_3 (6 to 8 *N*) for fraction collection.

Column exchange is slow, and resin particle size is relatively large; resulting in significant band spreading and potential overlap in matrix element and REE appearances. Large volumes of acids are required, introducing post–separation sample preparation steps and increasing time for analysis. High performance liquid chromatography (HPLC) is capable of reducing many of the problems found in open column systems. Control of flow rates results in significant decrease in separation time. The particle size of column packing material is reduced, increasing separation efficiency.

The combination of HPLC with ICP spectroscopic detection (OES and MS) is becoming increasingly popular; spectroscopic detection provides the sensitivity and the element selectivity needed to distinguish column effluents by chemical composition. It is especially powerful in the case of multi–channel OES or rapid MS detection, where "spectroscopic separation" can enhance chromatographic separation.

In our HPLC studies (Aulis *et al.* 1985), the HPLC outlet was connected directly to nebulizer inlet on the ICP–OES spectrometer. Chromatographic flow rates were matched to conventional nebulizer flow rates (1 to 3 ml/min). In order to obtain time–based data for all channels on the 36–channel spectrometer, the entrance slit "profile routine" (standard system software) was employed with the slit–drive stepping motor turned off. Because of acid concentration limitations to the HPLC instrumentation and the ion exchange column packing, aqueous solutions of $NaNO_3$ and $MgCl_2$ were tested as eluents. Separation tests indicated Mg^{+2} was preferable to Na^{+}, since lower concentrations of the Mg^{+2} counter ion could be used, and separations proved more efficient. Experiments with solutions of digested rock residues resulted in the development of a double gradient procedure to effect the separation. Matrix elements were removed by applying a small "burst" of Mg^{+2}, and after a brief water rinse, a second gradient increase was used to remove the yttrium and REE.

Linear calibration curves were obtained by plotting expected analyte concentrations (in synthetic rock base solutions spiked with REE) against chromatographic "profile" peak areas. Inter–REE spectral interference coefficients were obtained using conventional nebulization and applied directly to the chromatographic data. Yttrium and selected REE were determined for a number of reference materials and agreement was satisfactory. Determination limits (lowest quantitatively determinable concentration, LQD) were found to be: <1 ppm for europium and ytterbium; 1 to 2 ppm for lanthanum, dysprosium, gadolinium, and yttrium; 5 ppm for samarium; and 10 ppm for cerium and neodymium. Experimental results indicated that HPLC–ICP–OES could be applied to the determination of REE in geological materials. The technique does not involve fraction collection and reduces the need for constant operator attendance. The disadvantages of HPLC, including the need for a relatively large amount of instrument time, and the relatively poor determination limits compared to those for observed for open–column exchanged systems, indicated that this technique was not suitable for routine chondrite–level work.

In order to perform more efficient batch column ion exchange of REE in geological samples, K. Govindaraju of the Centre de Recherches Pétrographiques et Géochimiques (France) developed a robotic system, the LABROB, (Govindaraju, Lang, Mevelle and Janssens (1984); Govindaraju, Mevelle and Lang (1984)). This system consisted of a rack of small ion exchange columns and a rack of sample introduction tubes, with a computer–controlled robotic arm to move the racks between rows of sample, eluent, and collection vials. As the GLOGS was becoming recognized for its work in REE, the manufacturers of the LABROB invited it to evaluate the prototype system. Since the chemistry of the separation was the same as that used successfully with open columns (as discussed previously), most of the evaluation involved optimization of separation parameters and modification of software to introduce experimental flexibility. The LABROB system was found to be relatively successful for the separation of REE. However, the main problem with the system, i.e. the non–equivalence and irreproducibility of flow rates through the twelve columns and the subsequent need for manual intervention, led us to conclude that the prototype system did not offer any significant degree of improvement over the manual procedure.

SPECTROSCOPIC DETERMINATION OF THE RARE EARTH ELEMENTS

The spectroscopic technique first employed at the GLOGS for REE was based on the XRF method described by Eby (1972). Digestion of a rock sample with mineral acids was followed by ion exchange separation of the REE as described. Thulium (100 ppm) was used as an internal standard and added to the sample before decomposition. After decomposition and separation, barium (which was eluted from the column with the REE) was precipitated from the REE fraction (as $BaSO_4$), and the final solution evaporated on cation exchange resin loaded filter papers, which were then submitted for XRF analysis[1]. Examination of the wavelength tables for analyte lines, as well as potential interfering lines, indicates that extensive interference correction is required to correct XRF data. Each analyte requires individual calibration to obtain the required concentration and interference correction factors. The instability of the PW1540 spectrometer, made it necessary to monitor drift, and to use extensive recalibration and checking of interference coefficients. After XRF measurement at each analyte and interferent wavelength (for both sides of the sample paper), intensity data were corrected and converted to concentrations. Data were then normalized with respect to the thulium internal standard and (except for thulium) reported.

TABLE 86.1.

Element		Wavelength	Comment
Yttrium	Y	371.030 nm	most sensitive ICP line
Lanthanum	La	379.478	second most sensitive
Cerium	Ce	413.765	most sensitive
Neodymium	Nd	406.109	third most sensitive
Samarium	Sm	359.260	most sensitive
Europium	Eu	381.967	most sensitive
Gadolinium	Gd	342.247	most sensitive
Dysprosium	Dy	353.170	most sensitive
Ytterbium	Yb	328.937	most sensitive

The need for extensive interference correction and data normalization was a major impediment to accuracy of the method. Both sample preparation and XRF measurements were labour intensive and slow (e.g. >1 hour/sample to accumulate XRF counts); productivity levels averaged about 4 samples per technician–week.

The JY48P (Instruments S.A.) ICP–OES spectrometer system purchased by the GLOGS was configured to include selected REE channels (yttrium, cerium, lanthanum, neodymium, samarium, europium, gadolinium, dysprosium, and ytterbium) on the 36–channel polychromator. Each of the REE has many lines in the optical emission spectrum; in order to maximize the spectral information, especially for low concentrations of REE, it was important to choose analyte wavelengths of high sensitivity and as free from spectral interferences as possible. The following lines were chosen (*see* Table 86.1).

Recognizing that the high concentrations of matrix elements in rock samples would severely limit detection limits for REE, the sample preparation and separation steps used in the XRF method were adapted for ICP–OES analysis. After collection of the REE fraction from the ion exchange column, the solution was brought to dryness and the residue dissolved in a small volume of dilute acid (15 ml). This solution was then nebulized into the ICP, and the REE channels monitored. Sample through–put increased significantly, as the spectroscopic measurement time was considered trivial.

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[1] *The GLOGS method was developed originally for the Philips PW1540 XRF spectrometer (since replaced), using a tungsten target X-ray tube, an LiF(200) crystal, flow counter detection; count time at all peaks was 100 s.*

Detection and determination limits for the REE depend on the analyte wavelength used, and on the matrix of the sample solution and the need for interference correction. Instrumental detection limits (DL) reflect instrument stability under ideal conditions and are defined as 2σ of the background (or blank), are generally obtained from replicate measurement during a single nebulization of a pure (spectroscopic) standard. Determination limits, often expressed as "(lower) limit of quantitative determination" (LQD or LLQD), reflect the non–ideality of the sample, the need for interference corrections, and errors associated with sample preparation. They are often approximated as 5x the instrumental DL (or 10σ)[2]. LQD values for REE (ion exchange) determinations were reported (Bolton *et al.* 1983) to be: lanthanum, 0.5; cerium, 6; neodymium, 2; samarium, 2; europium, 0.1; gadolinium, 1; dysprosium, 0.5; and ytterbium, 0.1 (all in ppm rock). These values were similar to determination limits reported by Walsh *et al.* (1981) and Brenner *et al.* (1984), and indicate the procedure to be capable of measuring REE concentrations near chondrite levels.

Data for certified reference (rock) materials are conventionally used to assess the accuracy of an analytical method. Experimental results are often compared to values (or ranges of values) appearing in the chemical literature or in compilations such as that by Abbey (1980, 1983). CRM results have been reported by the GLOGS (*see* Bolton *et al.* 1983; Aulis *et al.* 1985) and by other groups (*see* also Walsh *et al.* 1981; Crock and Lichte 1982; Yoshida and Haraguchi 1984 (REE determinations by HPLC–ICP–OES); Brenner *et al.* 1984)[3]. The agreement observed between groups is often better than agreement with accepted values; this generally reflects the uncertainty in the "accepted" value, rather than the quality of experimental data.

ICP–MS DETERMINATION OF RARE EARTH ELEMENTS

The recently developed technique of inductively coupled plasma mass spectrometry (ICP–MS) has had considerable impact on the determination of trace elements in geological materials. Given the complexity inherent in the determination of trace elements in geological materials, the advantages of a mass spectroscopic technique in a relatively "affordable" form aroused a great deal of interest in the geo–analytical community. Among the first geo–analytical applications to be contemplated by laboratories in North America and Europe was the determination of "difficult elements", i.e. those requiring extensive pretreatment and/or elements present in low concentrations. In fact, REE results observed on the prototype system were instrumental in convincing GLOGS scientists of the benefits of acquiring an ICP–MS system. Because of its high sensitivity and the small number of (predictable) mass interferences, ICP–MS was felt to be well suited to the determination of chondrite level REE in solutions of digested geological samples, without the need for ion exchange separation. (For details on applications of ICP–MS, as well as a compilation of published data (to December 1987) on REE and other elements *see* Riddle *et al.* 1988.) Following the acquisition of an ICP–MS system in our laboratory, (ELAN Model 250 ICP–MS system –Sciex/Perkin Elmer), we examined the determination of REE in geological materials (Doherty and Vander Voet 1985); Doherty, in press).

The well–recognized advantages of ICP–MS include: a) excellent sensitivity (detection limits, typically <0.1 ppb in solution, which is better than those obtained by ICP–OES and comparable to those for graphite furnace atomic absorption spectrometry (GFAAS) (Selby and Hieftje 1987)) and wide dynamic range; b) analyte selectivity; c) spectral simplicity; d) low and uniform background; e) rapid, multielement capability; f) uniform instrument response over limited mass ranges; and g) isotope information (ratios, isotope dilution).

As most elements have at least one isotope of unique mass, and as many elements have a number of isotopes of reasonably high abundance, it is generally possible to select suitable analyte peak positions for selective analysis of a single element or a group of elements. There are relatively few mass (spectral) interferences, and, apart from polyatomic or multiple charged ions, these can be predicted and accounted for on the basis of isotopic mass and natural abundance data.

The application of ICP–MS to multi–element (REE) determinations in a complex and variable rock matrix illustrates some of the limitations of the technique, i.e. spectral and non–spectral interferences. The principal mass interferences are those due to isotopic mass overlaps and isobaric interferences. Interferences can also arise from other species present in the plasma or formed during the experiment, and may include diatomic oxide ions, doubly charged ions, and to a lesser extent, hydroxide, chloride, and other molecular ion species. Although they can be minimized by control of operat-

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[2] *Determination limits can also be obtained from 2σ calculations for replicate preparations of samples containing low levels of analyte (near the expected determination limit).*

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[3] *Tables of ICP-OES data are compared to literature and ICP-MS data in a review by Riddle and Vander Voet (in preparation).*

TABLE 86.2: CHONDRITE CONCENTRATIONS, ICP-MS DETECTION AND DETERMINATION LIMITS FOR RARE EARTH ELEMENTS

		Detection/Determination Limits (ppm rock)			
Element	Chon.[1]	I[2]	II[3]	III[4]	IV[5]
Y	1.96	0.02		0.004	0.05
La	0.330	0.05	0.002	0.004	0.03
Ce	0.88	0.05	0.002	0.005	0.03
Pr	0.11	0.05	0.002	0.004	0.03
Nd	0.60	0.18	0.009	0.003	0.14
Sm	0.181	0.15	0.006	0.02	0.13
Eu	0.069	0.07	0.003	0.001	0.05
Gd	0.249	0.14	0.011	0.018	0.3
Tb	0.047	0.03	0.002	0.004	0.05
Dy	0.325	0.13	0.007	0.015	0.2
Ho	0.070	0.03	0.002	0.014	0.05
Er	0.200	0.10	0.007	0.005	0.2
Tm	0.030	0.03	0.002	0.015	0.03
Yb	0.200	0.11	0.006	0.006	0.2
Lu	0.034	0.04	0.002	0.005	0.05

[1] *Chondrite values from Hanson (1980).*

[2] *Values from Doherty and Vander Voet (1985); determination limits based on 4 times standard deviation of counts at analyte positions for replicate blank determinations.*

[3] *Values from Lichte, Meier and Crock (1987); detection limits based on 3 times standard deviation of U background.*

[4] *Values from Doherty (in press); RR-ISCP-ICP-MS detection limits based on 3 times standard deviation of counts at analyte positions for replicate blank.*

[5] *Values from Longerich et al. (1987); detection limits based on 3 times standard deviation of background (Poisson counting statistics).*

ing conditions, these interferences cannot be eliminated and must be taken into account when selecting analyte isotope masses, and in data reduction. There are also a number of non–spectroscopic matrix effects, which appear to be dependent on the total dissolved salt content of the sample being introduced into the plasma (generally via solution nebulization). They include transport effects, ionization interferences, and ion–sampling effects (Riddle *et al.* 1988), and can result in errors in analytical accuracy.

Among the first geo–analytical data appearing in the literature were REE data for standard reference silicates, SY–3, GSP–1, and NIM–G, reported by Date and Gray (1985). This report illustrated, for the first time, the potential of ICP–MS to geological analysis. In 1985, Doherty and Vander Voet (1985) reported their initial results on the determination of yttrium and REE by ICP–MS and presented data for a series of reference materials, with generally good agreement between experimental and accepted values. The determination limits for rock digests (without ion exchange separation) were found to be at or below "chondrite levels", and are listed in Table 86.2). Rare earth element determinations by ICP–MS have been investigated at the USGS (Lichte, Meier and Crock 1987) and at Memorial University, Newfoundland (Longerich *et al.* 1987). Detection limits obtained by these authors are also tabulated in Table 86.2. Date and Hutchinson (1987) have also studied ICP–MS determination of REE, presenting data for a variety of reference materials.

Recently, Doherty (in press) has examined non–specific matrix interference effects and their effect on analytical error. In an extensive series of experiments, employing alternate skimmer designs[4] and including concomitant studies, he found that the level of analyte recovery (error in accuracy) was dependent on the analyte mass. Using the well characterized CRM BCR–1 (*see* Table 86. 3) as a primary reference, Doherty developed a double internal standard procedure using ^{99}Ru and ^{187}Re analyte peaks to bracket the REE masses. This Ru–Re internal standardization correction procedure (RR–ISCP) was able to compensate for many matrix environments, including samples spiked with exaggeratedly high "interferent" levels, and resulted in a significant improvement in long–term precision and accuracy required for routine analysis. The validity of the

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[4] *In experiments dealing with skimmer design, W. Doherty discovered that by blunting the skimmer lip (as opposed to the conventional knife–edge design), he was able to obtain significant improvement in sensitivity (factor 10 to 100 in detection limit) extended skimmer lifetime and improved long term instrument precision.*

TABLE 86.3: RARE EARTH ELEMENT CONCENTRATIONS (ppm) IN USGS REFERENCE BCR-1[a].

	OBSERVED						REFERENCED[d]					
REE	I[b]	II	III	IV	V[c]	V[c]	Ref.1	Ref.2	Ref.3	Ref.4	Ref.5	Ref.6
Y	28.7		29		35.40	35.90	35-40	39				38.5
La	23.2	26.7	22	27	24.80	25.10	24-27	25	26.60	25.30	25.0	25.3
Ce	50.8	54.4	50	57	53.70	53.30	50-59	53.7	53.80	54	53.7	52.5
Pr	7.0	7.0	6	7.6	7.26	7.37	6.4-7.3	6.9	7.29			6.68
Nd	27.8	28.9	24	31	28.40	29.20	25-33.5	28.7	29.70	28.60	28.7	30.5
Sm	6.6	6.80	5.2	7.8	6.54	6.74	6.5-7.1	6.6	6.70	6.70	6.58	6.69
Eu	2.2	1.99		2	1.99	2.03	1.9-2	1.96	1.98	1.95	1.96	2.01
Gd	6.3	7.10		7.4	6.66	6.70	6.3-7.0	6.7	6.90	6.63	6.68	6.78
Tb	1.0	1.08		0.6	1.06	1.09	1.0-1.2	1.05	1.00			1.07
Dy	5.9	6.59		6.7	6.43	6.63	6.3-7	6.35	6.72	6.30	6.35	6.34
Ho	1.3	1.29	1.14	1.3	1.34	1.36	1.2-1.4	1.25	1.40			1.29
Er	3.5	3.74		4.2	3.73	3.81	3.5-3.8	3.6	3.80	3.61	3.61	3.71
Tm	0.5	0.53	0.49	0.5	0.54	0.54	0.5-0.6	0.59	0.57			0.591
Yb	2.9	3.55		3.6	3.39	3.32	3.3-3.7	3.39	3.70	3.39	3.39	3.39
Lu	0.5	0.54		0.4	0.516	0.511	0.5-0.55	0.51	0.524	0.54	0.536	0.536

[a] *Values for BCR-1 are tabulated extensively as there is a reasonable amount of high quality, i.e. benchmark data (IDMS) for comparison.*

[b] *Experimental Data from I (Doherty and Vander Voet 1985); II (Lichte, Meier and Crock 1987); III (Longerich et al. 1987); IV (Date and Hutchinson 1987); V (Doherty, in press).*

[c] *RR-ISCP data from Doherty (in press) using two different skimmer designs.*

[d] *Reference values include: Ref. 1 = Range of reference values quoted in Doherty and Vander Voet (1985); Ref. 2 = Govindaraju (1984); Ref. 3 = ICP-OES data (with ion exchange) used for comparison in Lichte, Meier and Crock (1987); Ref. 4 = ID-MS data from Hanson (1976) (quoted in Lichte et al. 1987); Ref. 5 = IDMS data from Gladney, Burns and Roelandts (1983); Ref. 6 = NAA data from Gladney, Burns and Roelandts (1983).*

method was substantiated by the REE concentration values submitted in the certification program for the reference material (IWG) AC–E (Govindaraju 1987). Values submitted are compared to those submitted for isotope dilution mass spectrometric (ID–MS) measurements and "proposed" values in Table 86.4 . Data for other CRMs indicate excellent agreement with previously reported and compiled values (Riddle *et al.* 1988).

As a consequence of the quality of the data obtained in these studies, the GLOGS has adopted the RR–ISCP–ICP–MS method for the routine determination of yttrium and REE. The main features of this current method include: a) acid decomposition of the sample[5]; b) addition of internal standard elements; c) analyte calibration with pure spectroscopic standard solutions (including evaluation of interference contributions); and d) instrument (drift) control using CRM BHVO–1. Data are corrected for instrument drift, mass interferences, and for internal standard recoveries. Current detection limits are listed in Table 86.2.

The Geoscience Laboratories Section has had extensive experience in the determination of REE in

TABLE 86.4: COMPARISON OF CONTRIBUTED ICP-MS REE VALUES[1] TO CONTRIBUTED IDMS VALUES AND SUGGESTED VALUES FOR IWG REFERENCE MATERIAL AC-E

REE	Contrib.[2]	Comp.[3]	IDMS[3]
Y	185	184	
La	62	59	
Ce	160	154	156.3
Pr	23.50	22.2	
Nd	92	92	93.1
Sm	25	24.2	24.7
Eu	2.05	2.0	1.93
Gd	28	26	26.3
Tb	5.10	4.8	
Dy	32	29	30.5
Ho	6.60	6.5	
Er	19	17.7	18.4
Tm	2.80	2.6	
Yb	18	17.4	17.7
Lu	2.50	2.45	

[1] *All concentrations in ppm*

[2] *Contribution from Geoscience Laboratories, OGS.*

[3] *Comp. = recommended values and IDMS contributions as listed in Govindaraju (1987).*

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[5] *Quality of decomposition is monitored by a) a semi-quantitative XRF "screen" to define matrix composition, and flag potentially high amounts of elements associated with acid-insoluble minerals; and b) ICP-MS semi-quantitative determination of zirconium in solution. Comparison of the zirconium results by XRF and ICP-MS is used to identify difficulties in sample preparation. ICP-MS results for yttrium can also be compared to XRF "screen" results to monitor quality of decomposition.*

geological materials. Experience from early developments in XRF and ICP–OES methodology, as well as pioneering studies in the field of ICP–MS, has culminated in the current RR–ISCP/ICP–MS method. Rare earth element data for reference materials obtained during the development of the method are considered comparable to results obtained by ID–MS – considered by many to be a "benchmark" technique. Data obtained on a routine basis can be considered among the best available.

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